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Nat. Hist. Survey

R E P O R T

OF THE

EIGHTH ROCKY MOUNTAIN CONFERENCE

OF ENTOMOLOGISTS

PINGREE PARK, COLORADO

AUGUST 17 TO 22, 1931

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A Report of the Eighth Rocky Mountain Conference of Entomologists Pingree Park, Colorado, August 17 to 23, inclusive, 1931

The meetings were held in the Colorado Agricultural College Forestry Lodge in Pingree Park, about 55 miles by auto from Fort Collins. Many of the out of state visitors were traveling by automobile and the most of these arrived in Fort Collins, during the afternoon of Sunday the 16th or early in the morning of the 17th. The trip to the Park was made during the forenoon of the 17th, the most of the cars arriving in time for a late lunch. The afternoon was a busy one in making camp, especially as the crowd proved to be somewhat larger than anticipated, totaling 86, and over-flowed the Lodge and bunk house. A hurried trip to "civilization" produced two tents and some bales of straw. The young "bucks" declared this was the way they wanted to camp anyway so everybody was happy.

The following is a list of those in attendance:

Lester Hanna	Del Norte, Colo.
Albert White	Fort Collins, Colo.
E. G. Kelly and family	Manhattan, Kansas.
John L. Hoerner and Family	Fort Collins, Colo.
Geo. A. Dean and family	Manhattan, Kansas.
R. L. Parker and family	Manhattan, Kansas.
Roger C. Smith and son Phillip	Manhattan, Kansas.
Paul B. Lawson and daughter Lois	Lawrence, Kansas.
Dorothy Osborn	Delphos, Kansas.
Jean Sutherland	Boulder, Colo.
Edwin W. Howe and family	Wichita, Kansas.
R. G. Richmond	Fort Collins, Colo.
E. W. Davis	Salt Lake City, Utah.
H. E. Dorst	Salt Lake City, Utah.
K. D. Arbethnot	Monroe, Michigan.
J. H. Newton and family	Paonia, Colo.
Donald A. Wilbur and family	Manhattan, Kansas.
Chas. M. Drage	Loveland, Colorado.
Miriam A. Palmer	Fort Collins, Colo.
F. E. Whitehead	Stillwater, Okla.
Geo. M. List	Fort Collins, Colo.
F. T. Cowan	Fort Collins, Colo.
C. P. Gillette	Fort Collins, Colo.
Florence G. Malcouronne	Fort Collins, Colo.
Rellie G. Mack	Fort Collins, Colo.
Sam C. McCampbell	Fort Collins, Colo.
Louis G. Davis	Grand Junction, Colo.
Leland Jones	Salt Lake City, Utah.
Richard C. Newton	Salt Lake City, Utah.
Geo. I. Reeves	Salt Lake City, Utah.
John C. Hamlin	Salt Lake City, Utah.
Ralph Bunn	Salt Lake City, Utah.
John Weaver	Fort Collins, Colo.
Leslie B. Daniels	Fort Collins, Colo.

C. W. Kearns.....Fort Collins,Colo.
Harold Willis.....Fort Collins,Colo.
M. C. Parker.....Madison, Wis.
R. H. Beamer and family.....Lawrence, Kansas.
J. O. Notingham.....Lawrence, Kansas.
H. T. Peters.....Lawrence, Kansas.
L. D. Anderson.....Morganville, Kansas.
M. W. Sanderson.....Lawrence, Kansas.
Carl A. Bjurman.....Fort Collins,Colo.
J. W. Horn and family.....Boulder, Colo.
Carl Hopkins.....Boulder, Colo.
C. R. Jones and family.....Fort Collins,Colo.
Jack Manweiler.....Fort Collins,Colo.

The group was called together about the fireplace in the Lodge for the first meeting of the week at 8:00 p.m. Monday, by Dr. C. P. Gillette, chairman.

Short talks were given by the Chairman, Dr. Jones, Mr. Richmond, Mr. McCampbell and others in charge of different phases of the work in caring for the crowd, in regard to the meals, bedding, fishing places and privileges, fire precautions in the forests, etc. Each entomologist was asked to stand and introduce himself, the members of his family or his friends that were with him and to tell something of his connections and work. The following committees were appointed: Program, P. B. Lawson, chairman, Geo. A. Dean and Geo. M. list; Resolutions, Roger C. Smith, Chairman, F. E. Whitehead and Geo. I. Reeves; Entertainment, F. T. Cowan, Chairman, with power to draft such other members as he might need.

As the program for the week had not been definitely formulated it was decided to defer formal papers until the next day, and to give the remainder of the evening to getting better acquainted. Dr. P. B. Lawson lead the group in a number of popular songs and thus established himself as the "pep" leader for the week.

Tuesday, August 18, 2:30 p.m. Geo. A. Dean presiding.

Several topics dealing with the codling moth had been sent in so the program committee arranged them in a group, making this meeting into the nature of a symposium.

Professor Dean gave a brief history of the codling moth developments during the last several years mentioning particularly the increased difficulty in control being experienced in many of the important apple and pear growing sections. The work of the National codling moth Committee, that was the out-growth of a need for closer cooperation and a quick means of exchange of ideas among the workers of the various sections, was reviewed.

Relation of Temperature and Humidity to Rate of Hatch of Codling-moth Eggs, Edwin W. Howe, U. S. Bureau of Entomology, Wichita, Kansas. These remarks are based upon experimental incubation of nearly seven thousand codling-moth eggs under constant temperature conditions at the Wichita station of the Bureau of Entomology, United States Department of Agriculture.

Data obtained to date plainly indicate that humidity exercises an important effect in determination of rate of hatch. Within certain limits, an increase in the percent of relative humidity increases the rate of hatch. A reversal of this effect is noted as saturation is approached. Apparently, for a given constant temperature at which hatch occurs, there is an optimum percent of relative humidity. This is in accord with the conclusions of Pierce (1913), but differs materially from those of Glenn (1922), who assigned to the factor of humidity a role of minor importance.

Humidity apparently affects not only the rate, but also the percent, of hatch of codling-moth eggs. Eggs incubated at 95 degrees F. and at an average relative humidity close to 50% gave no hatch, while eggs incubated at the same temperature but at an average relative humidity of nearly 90% gave a small percent of hatch. Similar results were obtained at other temperatures, especially at 92 degrees F.

The term, "effective day-degree ", used by Glenn as a measure of accumulated temperature, and being designated by him as one degree of temperature above 50 degrees F. and below 88 degrees F. maintained for a period of twenty-four hours; is open to objection in that, apparently, it is not of exactly equal value at all temperatures between these two. However, as a practical measure of accumulated temperatures, it seems difficult to improve upon it.

Glenn concluded that at temperatures above 88 degrees F., rate of hatch was retarded at approximately the same amount for each rise of one degree as by each drop of one degree below this point. That is, that rate of hatch at 90 degrees F. would be approximately equal to rate of hatch at 86 degrees F. This viewpoint is also shared by Shelford (1927). Data obtained at the Wichita station to date, do not confirm this viewpoint, increase in rate of hatch continuing to 90 degrees F., while at 92 degrees F. there is only a slight increase in the total number of accumulated effective day-degrees to time of hatch.

Upper lethal temperature is close to 95 degrees F., while, under conditions of low humidity (approximately 50%) there is a distinct lethal effect at 90 degrees F.

While it is admitted that, for purposes of calculation, Glenns' figure of 50 degrees F. as, "developmental zero", may be approximately correct, it seems evident that the actual zone at which development of the embryo begins is below this figure, possibly close to 44 degrees F. Glenns' term, "developmental zero", is subject to criticism in that it indicates a fixed point

at which development begins. Actually, this point is not only probably below 50 degrees F., but must vary with individual eggs. The term, "developmental threshold", therefore, seems preferable.

References: Glenn, Pressley A., 1922 - "Codling-moth Investigations of the State Entomologists' Office"(Ill.), 1915, 1916, 1917.

Pierce, W. Dwight, 1916 - "A New Interpretation of the Relationships of Temperature and Humidity to Insect Development."

Shelford, Victor E., 1927 - "An Experimental Investigation of the Relations of the Codling-moth to Weather and Climate."

E.W.H.

Codling Moth Control in Kansas, R. L. Parker, Kansas State College of Agriculture and Applied Science. A few years ago, at the time this project was instigated, a problem of spray residue bobbed up and the main work of the project was side-tracked for a time to test the relative merits of different stomach poisons for the control of the codling moth, and at the same time, through these sprays, lower or eliminate, if possible, the arsenical residue on apples.

In this work, arsenate of lead has been found to be the "old stand-by." Experimental work carried out used the following weights of arsenate of lead to 50 gallons of water: 1, 1½, 2, 2½, and 3 pounds per unit. It was found that the most practical control from the standpoint of the cost of production was with two pounds of arsenate of lead to 50 gallons of water.

The following are some of the more important substitutes which were used in place of arsenate of lead in an attempt to control the codling moth in the lower Arkansas River Valley: A calyx spray of arsenate of lead was applied to all plots at the rate of two pounds of arsenate of lead to 50 gallons of water. The cover sprays which followed were then of a substitute. These are listed in the order of best control: Pyrethrum oil mixture in the cover sprays with a third cover spray containing nicotine sulphate; zinc arsenate; calcium arsenate; barium arsenate; magnesium arsenate; colloidal zinc; cryolite; and London purple. The magnesium arsenate gave very little control in this region. The calcium arsenate, colloidal zinc, cryolite and London purple caused a burning of the foliage.

Another phase of the work, known as the timing experiment, which follows out with the application of arsenate of lead at the rate of two pounds to 50 gallons of water every 12, 14 and 16 day interval. It has been found that the most practical timing is the 14 day timing.

Supplementary controls have been carried out with burlap bands treated and untreated. The bands were treated with beta

naphthol in a carrier of red engine oil. Also paper bands were used which had been treated with beta naphthol. The treated tight-fitting burlap band was by far the best. The treated paper bands would be desirable if they did not stretch when water came in contact with them. It is quite necessary that the bands be tight to attract the codling moth larva when it is seeking a place for pupation or hibernation. Such treated bands are known as automatic bands, since after the larvae enter them they are killed. The beta naphthol mixture does not act as a repellent.

R. L. P.

Status of the Trichogramma Experiments, Geo. M. List, Colorado Agricultural College. A project on the rearing and the use of Trichogramma minutum Riley in the control of the codling moth was started at the Colo. Exp. Sta. in the fall of 1927. A review was given of some of the experiences especially in the laboratory, the liberation being discussed more fully by the two following speakers. The attempt has been to rear the parasites in only such numbers as needed in certain experimental orchards. The unit system of rearing the Angoumois grain moths has been found the most satisfactory. The units consist of cabinets, each holding about 400 pounds of wheat, in which the temperature and humidity are controlled within certain ranges.

The mite Seiulus pomi Parrot, the cadelle beetle Tenebroides mauritanicus Linne. and the cucujid Cryptolestes ferrugineus Steph. have been problems in the cabinets, all being enemies of the grain moth. The parasites have been reared in an incubator in which the temperature was maintained at about 82 degrees F. and the relative humidity 70 degrees. The effect on the parasites of certain foods was discussed. Something over 3,000,000 parasites were liberated in the experimental orchards in Mesa and Delta counties, during June, July and the fore part of August.

G.M.L.

Codling Moth Control in the Grand Valley of Western Colorado, Louis G. Davis, Colorado Agricultural College. A summary was given of some of the problems which are being studied in the Grand Valley. A major project has been the liberation of Trichogramma minutum in an effort to determine its value as an egg parasite. Methods of liberation and of checking the results were reviewed.

Other projects include the use of Hootch traps in determining spray dated, determining the time of hourly checks of the greatest moth flight, chemically treated bands as a supplementary control, the use of Cryolite or Barium fluoaluminate and Barium fluosilicate as possible substitutes for lead arsenate in the control of the codling moth.

L.G.D.

Codling Moth Problems in Delta County, Colorado, J.H.Newton, Colorado Agricultural College. The liberations of Trichogramma minutum have not been as extensive here as in the Grand Valley. Results are more difficult to determine as codling moth infestation is lighter. Results secured by a definite control program carefully carried out in an orchard owned by the Agricultural College were reviewed.

Tuesday, August 18, 7:30 p.m. F. E. Whitehead presiding.

Travelogue of the Philippines, C. R. Jones, Colorado Agricultural College. Touching on various phases of life in Manila; the various tribes of the Islands, modes of living, industries and sports of the Philippino, and the various insect problems emphasizing that of the migratory Locust.

Wednesday, August 19, 8 a.m. C. P. Gillette presiding.

Symposium on Grasshopper Control. The serious grasshopper outbreak in the intermountain and North Central States made this an important subject for discussion, so the entire forenoon was given to it.

The Effect of Arsenic, As Used in the Control of Grasshoppers, Upon Birds, F. E. Whitehead, Oklahoma Agr. Exp. Sta. Chickens were placed in pens, and bran mash containing 5 pounds of arsenic per hundred pounds of mash was scattered in the pen at the rate of 50 to 100 pounds per acre. Another experiment was conducted in which 20 pounds of arsenic per hundred pounds of mash was used. The bran was well scattered, and the chickens had been without food for a period of 24 hours, but in no instance did a fatal case of poisoning arise. Bran and arsenic were carefully mixed and the amount of poison bran eaten by individual grasshoppers was observed. By this method a more or less rough estimate of the amount of arsenic consumed per hopper was determined, also the amount of arsenic to constitute a lethal dose for the chickens used was determined by feeding tests.

The information obtained from these experiments, together with the numbers of grasshoppers chickens were observed to eat, indicated that there is no danger of chickens receiving a lethal dose of arsenic from eating poisoned hoppers. This point was checked, however, by the following experiments.

Grasshoppers were poisoned in cages, using both white arsenic and sodium arsenite at the recommended rates and fed to small chicks and chickens of various sizes and breeds up to full grown chickens. Some had other foods in addition to poisoned hoppers, while others lived exclusively on poisoned grasshoppers and water for a period of ten days. Those eating other food in addition to poisoned hoppers were kept on this diet for varying periods of time up to sixty days.

In no instance did a fatal case of poisoning occur. Similar experiments were conducted with turkeys, ducks, and quail, and similar results were obtained. Nesting birds of various species were also fed poisoned hoppers. In this case numerous deaths

occurred in both those eating poisoned hoppers and those eating unpoisoned hoppers, with more deaths occurring in those eating poisoned hoppers; however, the difference was not sufficiently pronounced to indicate significance.

F. E. W.

Grasshoppers in Colorado, 1931, F. T. Cowan, Colo. Agr. College. The grasshopper outbreak in 1931 proved to be one of the worst the state has ever experienced. Practically every county east of the Continental Divide was more or less infested and control work was necessary in every one. This outbreak had been building up for the past three years as can be shown by the amount of poison bait sent out from the Experiment Station at Fort Collins. This fact, aided by the long dry fall during 1930 and a scarcity of parasites, gave Colorado what might be termed a real "old fashioned" outbreak.

Some early organization work was done especially in Logan County, where a pest district was formed and preparations made for a cleanup campaign. Sedgwick County also formed pest districts as did Washington, Kit Carson and El Paso. Practically all of this work was done early in June so that by the last of the month poison operations were in full swing in practically all of the counties. The early start obtained by most farmers served to lessen the damage to crops a great deal. Little or no damage was done to winter wheat. Barley, oats and corn suffered most in the dry land while sugar beets, alfalfa and corn were damaged to some extent in the irrigated sections. The damage as a whole, tho, in the sections where poisoning was done was estimated to be very light, while in districts where the work was more sporadic the damage ran from 40 to 100 percent.

The bait used this year varied somewhat in different localities. In the irrigated sections the best results were obtained where molasses was used. In the dry land areas, however, no molasses was used and excellent results were obtained. Sodium arsenite, 1 quart to the 100 pounds of bran, was used as the toxic agent in most cases, altho in the sugar beet growing area much Paris Green was used. Some 12,000 two quart cans of sodium arsenite were shipped from the College during the season and almost half as much more was manufactured in the field. This latter method is much cheaper and in fact compares very favorably with the old method of using 5 pounds of crude arsenic to the 100 pounds of bran.

The time of day for scattering the bait was found to be a very important item in this year's campaign. Heretofore the farmers had been advised to start poisoning about 7:00 a.m., continuing operations until about 10:00 a.m. It was found this season, however, that during the hot weather of July and August, it was necessary to start poisoning at sunup in order to get the poison out in time to catch a feeding temperature. Usually by 7:00 or 7:30 o'clock the temperature had risen so high that the hoppers had left the ground and ceased feeding on the bait. More definite information will be gathered on this subject in 1932.

At the present time the outlook for 1932 is quite favorable. It is probable that little work will need be done in any of the eastern counties except those in the southeastern part of the state.

F. T. C.

The Grasshopper Situation in Kansas and the Results of a Correlated Program of Work in Extension, E. G. Kelley. Grasshoppers have not been unusually serious in Kansas largely due to the results from several years of educational work. Most sections are well posted on the methods of control and the importance of starting control work early. The regular Kansas formula for poison bran has been depended on. Even tho some other formulas may be just as effective or cheaper it is best not to be changing recommendations when people are familiar with a satisfactory one and have confidence in it.

The general program of extension work in entomology for Kansas was discussed.

Geo. A. Dean closed the discussion on grasshoppers by giving a brief summary of the points brought out, and a history of the development of the present day poisoning methods. There was much discussion of the time of day for scattering the poison, the concensus of opinion being that the poison should be available in a fresh condition for the first feeding of the hoppers in the morning. This feeding time varies with the season, weather conditions and other factors. In the semi-arid plains sections the feeding temperatures may be reached by sunrise or shortly afterwards. The bait should be scattered earlier than has generally been the practice. It was suggested that it would be an advantage if a single formula could be used in all of the grasshopper states.

Wednesday, August, 19, 1 p.m.

Parasites of the European Corn Borer in the Middle Western Area, K. D. Arbethnot, Bureau of Entomology, Monroe, Michigan.

A brief discussion of the Liberation Program in use throughout this area, giving the location of Liberation Points, Technique of handling parasites, size of colonies and distribution of parasites.

A resume' of the Recovery Program, including key points, support points, dispersion collections, size of collections, etc.

Brief mention of the parasites which have been recovered and a summary of their present status in this area.

K.D.A.

The Importance of Insects Affecting Pastures, Donald A. Wilbur, Kansas State College. With the considerable research that has been initiated during the past few years on pastures and pasture management, it is becoming necessary that entomologists properly evaluate the importance of pasture insects, understand

the relationships existing between pasture insects and the chief cereal crops, and, when making recommendations involving pastures, be sure that such recommendations are in accord with good pasture management. Biological studies of pasture insects show that many of the most serious pests of staple crops are at first pests of the grasses and go over to the staple crops as the grasses dry or become scarce or unpalatable, or as the numbers of the pests multiply. In this way the pastures serve as nuclei of infection for grasshoppers, cutworms, army worms, wireworms, white grubs, leafhoppers and many others. Again, pastures may serve as places for hibernation as in the case of the chinch bug. With the increased value of pastures as a source of cheap gains for most classes of livestock, the insect injury to the pastures themselves is attracting attention. The time element is an important factor in connection with pests of perennial grasses. Comparative light attacks at a time when the food reserves in the roots are low may prove more serious to the grass stand than much heavier attacks later in the season. There are many obscure insects found in pasture grasses that may change their hosts from grasses to closely related grain crops and become of major importance in a short time.

D. A. W.

Notes on Honey Locust Borers in Colorado, Sam. C. McCampbell, Colorado Agricultural College. The first record by the State Entomologist's Office of serious borer injury to honey locust in Colorado was from Cheyenne Wells in 1926. The first specimens taken were of Leiopus variegatus Hald, but in 1927 specimens of Agrilus difficilus Gory were taken at Cheyenne Wells in numbers exceeding those of Leiopus.

Observation over a period of five years seems to indicate that Agrilus is the primary offender. Where a high percentage of trees was found in a dead or dying condition, Agrilus was found present, this was not true of Leiopus in all groves examined.

Adults of these two borers have been taken from June until late in Sept. All stages have been observed of Agrilus. The egg stage has not been observed for Leiopus. Known distribution in Colorado is east of 104 degrees longitude. Honey locust the only host recorded. Serious outbreaks appear after seasons of severe drouth or hail injury.

In 1930 at Akron, Colorado, over 75 percent of the larvae of Agrilus died apparently from winter injury. Atanycolus rugosiventris Ash is an important parasite of Agrilus larvae.

Neoclytus acuminatus Fab. and Amphicerus bicaudatus Say occur on honey locust in the vicinity of Fort Collins.

S. C. McC.

Taxonomy of Anuraphis maidi-radicis Forbes (Corn root-aphis) and Allied Species, Miriam A. Palmer, Colorado Agricultural College.

Taxonomic differences between Anuraphis maidi-radicis, Anuraphis middletonii Thos. (the Rigeron aphis) Anuraphis menthae-radicis and Anuraphis senecio-radicis Gillette and Palmer, illustrated by drawings. In viviparae the only differences are length of cornicles and antennal joints, and numbers of sensoria on antennae. These characters intergrade and are not entirely satisfactory. In the sexual generations clearly distinguishing characters occur in the hind tibiae of oviparae and the alate or apterous condition of the males.

M. A. P.

Wednesday evening, P. B. Lawson presiding.

Professor Geo. A. Dean gave a very interesting account of a recent European trip emphasizing observations made on agricultural conditions and practices especially those dealing with entomology.

Thursday, August 20.

It was decided to have no meetings this day but to give it entirely to collecting, fishing, hiking and other forms of recreation. All were given their lunch in a convenient form for carrying and the camp was much deserted. The evening had been designated as stunt night so some of the groups took advantage of the opportunity and it is said that even rehearsals were held. The five stunt leaders that had been appointed by the entertainment committee were K. D. Arbethnot, Geo. I. Reeves, J.H.Newton, Vice E. G. Kelley, Roger C. Smith, and F. E. Whitehead. Five very entertaining, if not instructive, stunts furnishing one and one half hours of very enjoyable entertainment were presented. The entomological classification of the "bugs" present received the most votes as the best stunt. The new species described were credited to Dr. Hamlin.

Friday, August 21, 8:30 a.m., Geo. M. List presiding.

Symposium.- Mathematical Analysis of Entomological Data.

Note: The custom has been to give in the reports of the Conference only abstracts of the papers or talks presented, but we take pleasure in giving in full two papers that were presented in the symposium.

Geo. M. List, Secretary

The Use of Mathematics in the Alfalfa Weevil Investigation

By
Geo. I. Reeves and Dr. J.C.Hamlin,
U.S. Bureau of Entomology

The Alfalfa Weevil Investigation has been much criticised for its failure to publish the mass of data which must have accumulated in twenty years of continuous observation of a single species. Farmers' bulletins outlining a satisfactory system of practical control have been published and advice has been given to many investigators which has helped them with various studies of the alfalfa weevil, but no thorough-going ecological analysis of the alfalfa weevil has been made. I am glad that it is to this gathering of men who are not only my friends but also entomologists especially concerned with the alfalfa weevil that I can present the first ecological analysis of the species. The fitness of this subject as a contribution to the symposium on the mathematical attack of entomological problems will appear as we proceed.

The reason why none of the data upon the relation of the alfalfa weevil to its environment, or only the merest sketches, have been published is that, as all students of the alfalfa weevil know, the data have been apparently contradictory. Our theories as to the effect of weather conditions, parasitism and farm operations, while clearly founded upon a sound conception of the facts, were overturned year after year as often as we put them to the test. We dealt with such anomalies as a parasitism of 99% which still failed to control the host; and a host with an enormous rate of multiplication whose numbers were still apparently self-limited after the first few years in a given locality. The most consistent possible conformance to weather conditions one year was followed by apparent disregard of all such influences the second year.

The principal outlines of the life history had already been worked out by Doctor Titus before I became interested in the problem, and my task was at first to fill in the missing links in hopes of hitting upon the strategic point which had not yet been discovered. As a result of this work, the spraying and dusting method of control, which was something of an innovation as used upon forage crops, was produced, but it has never been so widely useful as it ought to be because the essential relation between the pest and the climate was still unknown, and weevil attacks could not be foreseen and control campaigns adequately prepared. The keynote was lacking.

In 1912 Harry S. Smith planned some hibernation experiments, in which the entire weevil population of certain 2-square-yard areas taken at different times throughout the winter was counted. Practical difficulties interfered with this attempt, and it has never yet been successfully carried through, but it furnished the inspiration for a similar series of observations which were performed throughout the summer of 1913 upon the population of growing fields. At the cost of an enormous amount of drudgery, a complete census of a square foot of an alfalfa field was taken

each week throughout the entire season, and our ideas of the rough seasonal history of the species were considerably corrected; but no meteorological observations accompanied this survey, and attempts to correlate our figures with the Weather Bureau averages of a station several miles distant were, of course, unsuccessful. The principal result of this season's work was a method of comparing the population of sprayed plots by sweeping and counting the larvae, which, in spite of its serious defects, was useful during the years 1913 to 1918.

The trustworthiness of this method of estimating the population of a field came up for discussion between Mr. Hyslop and me a few years ago, and Mr. Hyslop visited us at Salt Lake partly for the purpose of testing the sweeping method of estimating field populations. In the discussions which followed Mr. Hyslop's visit, Doctor Hamlin and I canvassed the recent literature dealing with the mathematical treatment of entomological data, and after throwing out the authors whose purpose was clearly to mystify the reader and exhibit their own erudition, together with those who were applying, as rules of thumb, formulae which they evidently did not understand, we arrived at a nucleus of workers - largely inarticulate creatures - who unmistakably knew what they were about. After translating their statistical rigmarole into English so as to uncover the beautifully simple and clear ideas which underlie it, we were convinced that mathematical treatment could be applied as well to entomology as to the other biological sciences in which it has given such remarkable results, and we were further convinced that it was especially necessary in the case of the alfalfa weevil.

We accordingly began the weekly collection of 8 square-foot samples from a field selected because of its typically abundant weevil population, and we have continued the collecting and counting of these samples throughout three years. The operation consumes, besides a considerable amount of my time, the greater part of Doctor Hamlin's - much more than the official daily eight hours - and considerably more than the official full time of from four to six other men who do the laborious and responsible work of gathering and examining the samples. Tabulation of the results, if it were constantly kept up to date, would employ practically the full time of one man at a calculating machine.

The labor has, however, been mitigated since the very beginning by the obvious emergence of interesting results, and eventually it has brought out an obscure fact which could hardly have been discovered by any other means, but which furnishes the key to the alfalfa weevil's relation to its environment. This fact is that every year a certain insignificant part of the species hatches too late to be killed by parasites or by the heat of the stubble-fields, feeds unnoticed upon the second crop instead of the first, and, after most of the enormous first-crop population has perished, survives to furnish the nucleus for the next generation. Furthermore, this important vestige can be regulated by adjusting the cutting of the first and second crops to the parasitic attack and the weevil's developmental schedule. So much for the practical results. The process is as follows:

The fluctuations from week to week of the various elements of the weevil population of the field, such as adults of the new and old generation, eggs, four stages of larvae, pupae and parasitic larvae, are plotted and compared with various meteorological and cultural influences, of the former of which temperature is the most important, and of the latter the cutting of the crop. This is done, not by trying to connect particular phenomena of insect growth directly with particular instances of weather behaviour, but by treating the particular instances of both as departures from the normal procedure, as shown by the history of all the available years.

For example, at the beginning of the season of 1930 the surviving adults, representing an inheritance from the previous year, numbered 5.59 to the square foot of alfalfa field. Late in April they began to disappear and by the end of August they were all gone. The steps of this change are shown by Figure 1, in which the dotted line represents the numbers of weevils to the square foot observed on each of the dates arrayed on the horizontal margin, and the solid line represents a 3-point moving average employed to neutralize the errors due to random sampling.

These survivors, the breeding-base of the species, with the breaking-up of winter were subjected to the action of climatic factors, best represented by temperature, whose effect was to promote egg-laying. The egg population, hitherto consisting of the few eggs laid the previous fall, increased slowly at first, and beginning the first of April rose abruptly to 593 per square foot on April 21, then more gradually to a peak of 733 on May 18, and finally fell to 335 just before the first cutting, which came June 9. After the cutting, a small and shrinking egg population, having a peak of 26 eggs per square foot, persisted until second cutting, July 29, 1930. It seems to be of special importance beyond all proportion to its size.

These fluctuations are shown graphically by the coarsely-dotted line in Fig. 2, whose shape suggests that it may approximate a normal distribution curve. Such a curve, of the type indicated by the equation

$$y = \frac{N}{\sigma\sqrt{2\pi}} e^{-\frac{x^2}{2\sigma^2}}$$

fitted to the observed egg values, is shown in the solid line, and its agreement with the coarsely-dotted line is obvious. These curves show that oviposition was nearly completed before the cutting of the first crop, indicated by the vertical line. They also call attention to the small, dwindling egg population after the first cutting, which, although numerically trivial, proves to be of the greatest practical importance.

Now, let us apply the same mathematical formula to the egg population of the 1931 season. Here the finely-dotted line (Fig. 3) represents observed values and the solid line, the mathematically computed curve. The shape of this surve is very different from that of 1930, but the fit again is excellent.

The 1929 season shows an egg curve of still another form, but fitting equally well the same equation. Hence we conclude that the egg population follows a normal distribution curve, and we shall be able to detect any deviations in future, thus opening the possibility of correlating such deviations with environmental factors.

A similar process is used in analyzing the larval population produced from the enormous egg population of the first-crop period. For 1930, this larval population as obtained from actual counts is shown by the finely-dotted line (Fig. 2), which, since the larvae are derived from the eggs, naturally parallels the left side of the egg curve. Again in 1931 (Fig. 3), the larval line is roughly parallel to the upslope of the egg curve. Doubtless these larval values would fit a curve of the normal frequency type which could be computed from the egg and the temperature curves, and used to forecast the resulting adult population, were their trend not always interrupted by the cutting of the first alfalfa crop, which usually occurs in early June in the Salt Lake valley. As it is, that portion of the curve which we do have is probably most useful when considered as a straight line.

This larval population, developing under the influence of climatic conditions from the egg population already charted, and tending to produce a certain adult population is subjected to a disturbance in the form of parasitism by Bathyplectes curculionis Thoms. Thus on May 1st, 1930, the fourth-stage larvae showed parasitism of 73.3% when the first ones appeared. The parasitism then rose to 98.8% on May 18th, and declined to 80.5% on June 6th just before the cutting of the first crop. The destruction of weevil larvae thus foreshadowed profoundly alters the outlook for weevil increase.

However, before parasitism brings about the death of the larvae, the cutting of the first crop produces drastic ecological changes in the alfalfa field, killing almost impartially both parasitized and unparasitized larvae (Fig. 4). Within one week after the cutting time in 1930 the larval population declined 96.6%. Only 2.4% of this reduction is accounted for by larvae developing into the cocoon stage, the remaining 94.2% of the decrease being due to heat and starvation; that is to say, cultural control. This kill operates on larvae of all stages and conditions, but 91.0% of the survivors are mature larvae. Some of these spin cocoons during the second week after cutting, and others succumb to the adversities of the stubble field, so that, two weeks after cutting, the larval population has almost disappeared. It is then renewed by the hatching of the eggs laid, after the first cutting, by the few surviving overwintered adults.

This is the dwindling egg population mentioned earlier in connection with the egg curve. These eggs, like the earlier ones, are laid mostly in litter on the ground; they produce a larval population which is represented in Figure 4 near the base line and between the two vertical lines with its peak, which comes 4 weeks after the first cutting, only one-thirtieth as large as the peak of the earlier larvae. This curve is inconspicuous, and the larvae which it represents are too few to be noticed in the field. They

owe their importance to their appearing after parasitism and the cultural kill have spent their force. Moreover, in spite of the shortness of the second-crop growing period, the temperatures are so high and larval growth consequently so rapid, that a large percentage of the second-crop larvae pupate and emerge before cultural kill again comes into play at the second cutting.

The consequence is that the cocoon population resulting from both the first- and second-crop larvae, shown by the finely-dotted line, in Fig. 5, presents a bimodal curve having its peaks near the vertical lines which represent the first-and second-crop cuttings. The first-crop population, culminating June 16, is the larger, reaching a height of 36.38 per square foot, but its members show a parasitism of 83.78 to 96.05% and a considerable heat kill, while the second peak, although much smaller, is affected by parasitism of only 8.08 to 8.70% and a negligible heat mortality. Actually therefore, the small second-crop larval division is more important than the larger first-crop population, a fact which is reflected by the numbers of living pupae resulting from the two groups; that is to say, the individuals which have escaped both biological and cultural kill, represented by the coarsely-dotted line in Fig. 5.

The importance of this second-crop cocoon population is finally established by consideration of the new-generation adult population, shown by the solid-line curve in Fig. 5. From it we see that the bulk of the adults which form the potential breeding-base for the succeeding year, and which do not appear until the first of August, have resulted from the long-overlooked, small larval population present on the second crop.

In the unsuspected significance of this population lies the solution to that perplexing question, how we could experience nearly perfect parasitism one year and still have sufficient new-generation adults produced to cause weevil injury the following year. The explanation is now simple: namely, that the apparently unimportant second-crop larval population is so little affected by either biological or cultural kill, that it serves to maintain the adult population at an economically dangerous level.

Another problem was presented by the fact that different fields in a small locality, although subject to the same weather conditions, would range all the way from slight to severe damage. The answer here is that the customary difference in cutting-dates of different farmers, amounting often to a week or more, makes a tremendous difference in the effectiveness of the cultural kill, without which the biological kill is inadequate. This condition also explains the result of a recent statistical study which showed that the adult population was homogeneous in individual fields but that there was a highly significant difference in abundance of weevils in different fields.

Many years ago the staff of the alfalfa weevil laboratory learned that only a portion of the new-generation female weevils were capable of depositing eggs during the fall of the same year they became adult. The existence of two divisions of larvae, producing two distinct divisions of adults may explain this observation, for it is likely that only the adults of the first division

are capable of ovipositing in the fall, their younger sisters not reaching sexual maturity until the following spring.

In regions where weevil damage is customary and serious, farmers are compelled to time their cutting by the stage of injury instead of the stage of growth; and even where the damage is less regular, and early cutting less necessary, it is practiced to a considerable degree. The purpose is to save the existing crop, but the practice also indirectly reduces weevil damage the following year, and it is probable that by this means the farmers of infested localities, after contending with the weevil for several years, unwittingly lower the weevil population and give foundation to Doctor E. D. Ball's surmise that weevil injury automatically tended to subside within 4 or 5 years after its first appearance.

From the foregoing discussion it must be clear that field studies planned and executed in accordance with the requirements of mathematical analysis have revealed the mechanism whereby the weevil continues its existence in fluctuating abundance from year to year. It is equally clear that the results point definitely to cultural control of the species by modification of existing harvesting practices. Experiments to this end are scheduled for the coming season.

It now remains but to illustrate the methods of mathematical analysis which we have employed in our study; these examples are presented in the succeeding paper.

The Mathematical Approach to Insect Problems

By

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Mathematical analysis has up to the present time been found useful in three conspicuous problems connected with the alfalfa weevil, two of which are of immediate practical application and the other possibly of still greater eventual importance. These are, the relation of temperature to the increase of the species, the effectiveness of the imported parasite, and the conception of a base curve of temperature in reference to which all such phenomena can be studied. Underlying the treatment of these problems is the idea of carefully planned and precisely executed observation and collection methods as a foundation for mathematical analysis.

Relation of Temperature to Increase

The primary factor in weevil increase is plainly the rate at which eggs are produced, and its dependence upon temperature has long been vaguely recognized. The obvious method of approaching a quantitative study of this process would be to observe the fluctuations in the egg population throughout the season as it follows the normal frequency curve shown in Figs. 2 and 3. Unfortunately for this purpose, the egg population, although it increases exclusively in response to oviposition, will not serve as an index thereof because it is constantly depleted by other causes, chief of which is the hatching of the eggs.

This difficulty is avoided by using the increase of the total immature population as a measure of the oviposition. The larval stages, like the egg stage, suffer diminution by the natural progress of the individuals from stage to stage and finally to maturity, but the earlier steps leave the total unchanged and the last one does not happen until after the cutting of the first crop has itself temporarily halted this phase of the investigation.

The average immature population is accordingly plotted in Fig. 6 as the dependent variable against the accumulated effective day-degrees Fahrenheit. This unit is computed with the planimeter from thermograph records taken at ground level in the alfalfa field, assuming, upon considerable evidence, that 50° F. is for this purpose the threshold of development. Using this unit instead of the time-unit employed in Figs. 2 and 3 gives each week weight in proportion to its average temperature, instead of assuming them all equally effective in promoting the increase of the immature population. It removes weekly fluctuations caused by varying weather conditions and discloses the dependence of oviposition upon temperature; and it excludes normal developmental changes, limiting to actual mortality the significance of apparent decreases in the population.

The dots represent the number of eggs and larvae present from February 17 to June 6, 1930, and the crosses, the corresponding

values for 1931. The fact that the dots and the crosses, respectively lie in nearly straight lines sloping at an angle of 45° to the horizontal, indicates that, from early spring to within two to four weeks of the first cutting, the immature population increases in direct proportion to the accumulated day-degrees of effective temperature.

The departure from these lines, in the last two values before cutting in 1930 and the last four in 1931, at a time when no larvae had yet passed over into the adult stage, shows that some component of the immature population had perished; and additional records indicate that the mortality was among the new-hatched larvae. It is believed that the explanation lies in the unusually long period, 21 to 28 days instead of 10 to 14, between the heading-out of the alfalfa and the cutting of the hay crop, during which time the maturing and hardening tips were unsuitable for the entrance of the young larvae.

Besides the general correlation between accumulated temperature and oviposition, and the departure caused by the ripening of the crop, another discovery, still unaccomplished, is foreshadowed by the position below the line, of the three points,(914,277) (820, 296), and (822, 313) in 1930. Thus mathematical analysis has yielded precise corroboration of a long-suspected truth, has demonstrated the existence and found the cause of an unsuspected fact, and has indicated where to look for another discovery whose nature and importance we are unable to surmise.

Effectiveness of the Imported Parasite

The effectiveness of the ichneumonid parasite, Bathyplectes curculionis Thoms., is so interdependent with the temperature relations just described and with the killing effect of stubble-field conditions that all previous attempts to estimate it, by rearing host larvae and determining the so-called"percentage of parasitism", has resulted only in showing vaguely that the parasitism was large and yet often economically ineffectual. "Percentage of parasitism", as applied to larvae, and meaning the percentage at an arbitrarily selected moment or the average percentage for the season, is what Spencer called a symbolic conception, corresponding to no real idea; for the percentage of parasitism varies from hour to hour and is never an index either of the activity of the parasite or of the injury inflicted upon the host. Parasitism can be measured only by measuring its fluctuations; and it can be interpreted only by observing the relation of its fluctuations to the other influences which determine the rise and fall of the host species.

The former requirement involves first ascertaining the underlying facts, preferably by some less difficult and more accurate method than by rearing haphazard samples of larvae; the latter requirement necessitates basing the parasite analysis upon the same material that is used for the general ecological survey.

In the field which is being studied 8 samples, each containing all the population of a square foot, are taken on the first day of each week. For parasite study the larvae of each sample are sorted into the 4 larval stages on the basis of head size, and after thorough mixing of each stage a lot of 5 is drawn at random for dissection under the binocular microscope. Five such mixings and drawings are made in succession, and when the dissections have been made and the number of parasitized larvae has been recorded, the coefficient of variation for the given sample and stage is computed. If this exceeds a certain arbitrarily chosen value, additional sets of 5 lots of 5 larvae each are drawn and dissected to lower the coefficient of variability, the final percentage being based upon the total number examined. Thus a minimum of 200 from each larval stage are dissected each week when the samples provide so many, and enough more to bring the various lots to a high degree of uniformity.

The result appears in the low probable-error values of Table 1, which sets forth the mean percentage of parasitism of each larval stage for each week throughout the first-crop growing season of 1931. In this table, the probable error of the mean has been attached to all means derived from 50 or more larvae. It has been omitted in the case of "Cocoons", for which, as they were not handled in random lots, no measure of dispersion can be calculated.

The probable error of the percentages in this table is not only a measure of their trustworthiness but it also determines whether the differences between various values is significant or accidental. For this purpose the probable error of any difference is calculated by adding the squares of the probable errors of the two means and extracting the square root of the sum, as shown in the formula:-

$$PE_{(M_1 \pm M_2)} = \sqrt{e_1^2 + e_2^2}$$

where M_1 and M_2 are the two mean values and e_1 and e_2 are their respective probable errors.

Comparing, for example, the parasitism of 1st-stage larvae on April 27 with that on May 4, it appears that the difference between the mean percentages on those dates is 16.33, with a probable error of 3.47. The difference, being 4.7 times as large as its probable error, is by customary standards clearly significant. But comparing the percentages of this larval stage for May 4 and May 11, we obtain a difference of 7 ± 3.64; here the difference is only 1.9 times its probable error and therefore must be regarded as a fortuitous fluctuation.

In Table 1, the spaces between percentages of parasitism which are not significantly different are marked by Xs. In all other cases percentages which are either vertically or horizontally

adjacent differ significantly, or in other words, indicate a trend.

So considered, Table 1 shows that the maximum of parasitism obtained on May 20. The apparent decrease in parasitism of the 1st-stage larvae on that date is ignored because other data show that it was produced, not by a decrease in the number of parasites, but by an influx of newly-hatched larvae which diluted the parasitism. After May 20 the hitherto prevalent increase in parasitism gave place to a general decline which could be explained only by a large increase in host larvae or by diminishing activity of the adult parasites. Since the general ecological survey shows that there was no larval increase between May 20 and May 25, when the decline began, the decreased parasitism must mean deterioration of the adult parasites.

The continued reduction of parasitism after May 25, at first slight and not significant, indicating that Bathyplectes, though on the wane, was still able to maintain the then reduced level of parasitism, becomes after June 1 a general and significant decline, marking the last phases of the oviposition of the overwintered individuals of Bathyplectes, which have hitherto supplied all the parasitism. On June 8, however, the short-cycle members of the 1931 generation begin issuing. This reinforcement stops the rapid decline in larval parasitism, so that the percentages of June 15 are not significantly different from those of June 8.

At this point the cutting of the first crop of hay intervened to prevent any further development and fix the parasitism among the various stages at the figures shown in the last line of the table.

The last column of Table 1, "Cocoons", shows the percentage of parasitism of spun larvae, pupae and parasite cocoons within host cocoons. It is included partly because of the confirmation which, allowing for the ten-day lag between the stages, it furnishes for the percentages of the 4th-stage larvae; and partly also because the parasitism is slightly higher in the cocoon stages indicating that Bathyplectes adults attack some 4th-stage larvae.

This analysis of the fluctuations of parasitism and their relations to the season, the host species, and the farm schedule, may be completed by applying the same methods to the differences between the vertical columns of percentages in Table 1, which bear upon the selectivity of the parasitic attack as between larval stages. Mere visual inspection shows that parasitism is numerically higher in each successive larval stage, but does not show which increases are significant. The method above discussed, however, indicates that all these 19 differences are significant except 3, which means that Bathyplectes parasitism is a function of the length of exposure of the larvae.

The somewhat simpler method of Fisher,* while it fails to show the particular points between which the difference is not significant, is preferable for merely comparing two series of values, as presented in the following table:

Stages Compared	Mean Difference	Probability that Such Difference Resulted from Chance Variation
2nd minus 1st	+ 32.10	less than .01
3rd " 2nd	+ 25.37	" " .01
4th " 3rd	+ 9.52	between .01 and .02

While the percentage of parasitism increases with the age of the host larvae, it does not vary in direct proportion thereto, as is shown in Fig. 7 by plotting the average percentage of parasitism of each stage against the midpoint of the average period of life of that stage expressed as a percentage of the total larval period. The straight line, answering to the equation $y = x$, is obviously the one in which the values would lie if parasitism rose in direct ratio to the length of exposure of the larvae. The curved line connecting the observed values of parasitism, dropping as it does below the straight line at the upper end, shows that the fourth stage larvae, doubtless because of their tough skin, are exceptionally free from attack by Bathyplectes. This conclusion is further substantiated by direct visual observation in the field.

The Base Curve of Effective Temperature

That there is a fundamental relationship between temperature and insect activity is universally recognized, yet the greatest difficulty has been encountered in determining just what the relationship is for individual species, except perhaps under controlled conditions which depart widely from conditions in nature. The very profusion of temperature values, such as daily, weekly, monthly or annual maxima, minima, or means, for a single season in one locality hamper our interpretation of temperature effects, and when many localities are studied throughout a period of years the temperature data, even when somewhat reduced by plotting curves for the average of each locality with which any particular year may be compared, become so numerous that intelligent interpretation of the data is well-nigh impossible.

Confronted with this problem of devising a feasible method for studying temperature, we have endeavored to reduce the multiplicity of temperature data to a single curve representative of the usual seasonal trend. In doing this the number of effective day-degrees (above 50° F.) occurring during each week has been computed by planimeter from thermograph records taken at ground level in the alfalfa field. These values when plotted appear to follow the normal distribution curve, and we have therefore fitted to them such a curve, obtained from the formula

$$y = \frac{N}{\sigma\sqrt{2\pi}} e^{-\frac{x^2}{2\sigma^2}}$$

*Fisher, R. A. Statistical Methods for Research Workers. 2nd Ed. 1928. Oliver & Boyd, Edinburgh.

This theoretical normal curve, together with the actual curves for the years 1928, 1929, and 1930, is shown in Fig. 8.

Records, secured in situations inhabited by the weevil, which were available when this curve was constructed covered only the three years 1928 to 1930.* It will be seen that the heavy black line, representing the normal curve, provides a reasonably good fit for the aggregate of lines for the several years. Accepting this curve as the base curve of temperature, we are at once enabled to study distinct abberations therefrom in any particular year in relation to its effect upon weevil activity. For example, the effective temperatures during April, 1930, were much above those of the base curve. Let us now look at the egg population of that year.

Fig. 9 shows clearly that the excessive temperature in April was accompanied by a great increase in the egg population, as indicated by the finely dotted line. The midpoint of the topmost points on the egg curve obtained on May 5, which may be considered the peak of the curve, although the actual peak came later due to adverse weather during the first part of May. In 1931, on the contrary, Fig. 10 shows that there was no excess of temperature during April, but instead the day-degrees accumulated by the end of April closely approximated the sum of day-degrees on our base curve. We should, therefore, expect the egg peak to occur somewhat later in 1931 than in 1930; and the midpoint of the higher values on the egg curve actually did occur on May 20, about two weeks later than in 1930. It is also worthy of note that, although the excess of temperature in April, 1930, markedly advanced egg-laying, the average deposition per female was only slightly over half that of the 1931 season when the temperature approximated the base curve.

It may be added that the base curve of temperature, itself a normal frequency curve, was successfully used in conjunction with the normal egg-population curve in forecasting the egg population later determined by actual counts during the present season. This operation requires, of course, knowledge of the magnitude of the breeding base.

Another example of the utility of the base curve of temperature is its use in forecasting the date of first cocooning. Knowing the date of appearance of first larvae, the base curve serves to indicate when a sufficient number of day-degrees to mature these

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* Since presenting this paper we have had an opportunity to calculate the base curve including the 1931 temperatures. The two curves are practically identical as may be noted from comparing the means and the standard deviation, the vital element of the formula. For the three-year curve the mean was 24.5 weeks from our starting point, and in the four-year curve it was 24.3. The standard deviation, calculated from the three-year data was 7.16, while the inclusion of the fourth year changed it to 7.09.

larvae will have obtained; the date so indicated is then subject to advancement or retardation according to whether the abberations from the base curve are positive or negative. This procedure was employed with the greatest success during the current year.

Having secured and used the base curve of temperature, we were puzzled to reconcile its exponential character with the physical basis of weather conditions. That it fitted the facts we were reasonably satisfied---at least in so far as was possible on the basis of only three years' temperature records--yet it seemed a purely arbitrary representation of those facts. But we found upon study that the base curve, approximating a normal frequency curve, may be equally well represented as a complex periodic curve, Fig. 11, of which the fundamental elements is a sine curve representing the recurrent seasonal exposure of the northern hemisphere to the sun, modified by a phase displacement representing the lag in the approach of spring due to the earth's specific heat, and further modified by a sine curve of shorter wave length representing the weather fluctuations which can be observed in the records of individual years and which in northern Utah are extremely regular.

These curves are, from the entomological viewpoint, largely metaphorical, but they do serve to show that the activities of the alfalfa weevil are controlled by influences which are not spasmodic or accidental, but as deeply fundamental as the movement of the planets themselves.

FIG. 1. DECLINE OF OVERWINTERED ADULT POPULATION.

FIG. 2. THEORETICAL CURVE OF EGG POPULATION(1930)

FIG. 3. THEORETICAL CURVE OF EGG POPULATION (1931)

FIG. 4. LARVAL POPULATION

FIG. 5. BIMODAL CURVE OF COCOON STAGES

FIG. 6. IMMATURE POPULATION IN RELATION TO TEMPERATURE

FIG. 7. PARASITISM IN RELATION TO AGE OF LARVAE

FIG. 8. BASE CURVE OF TEMPERATURE

FIG. 9. 1930 EGG POPULATION & TEMPERATURE CURVE

FIG.10. 1931 EGG POPULATION & TEMPERATURE CURVE

FIG.11. PERIODIC TEMPERATURE CURVES

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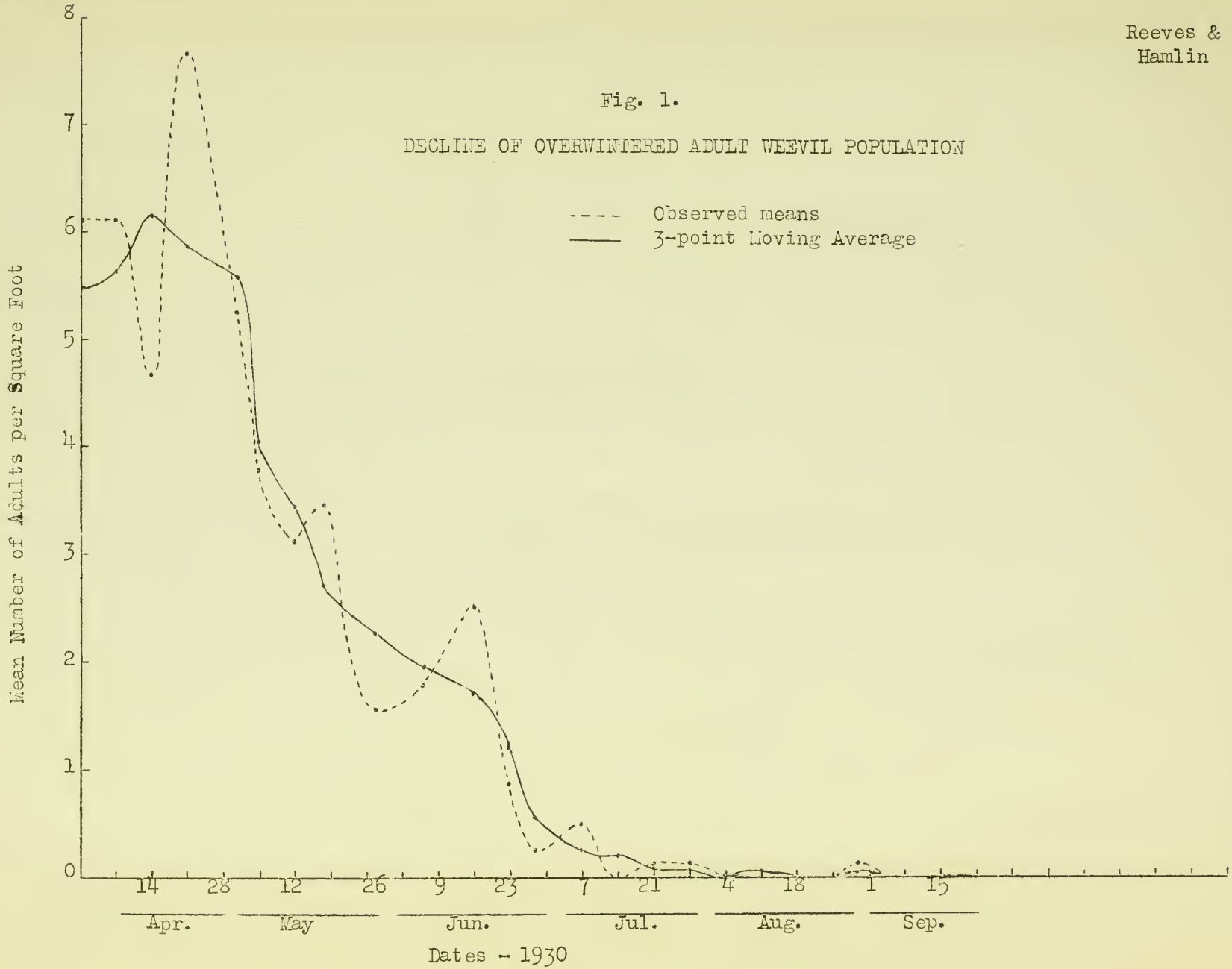
Fig. 1.

DECLINE OF OVERWINTERED ADULT WEEVIL POPULATION



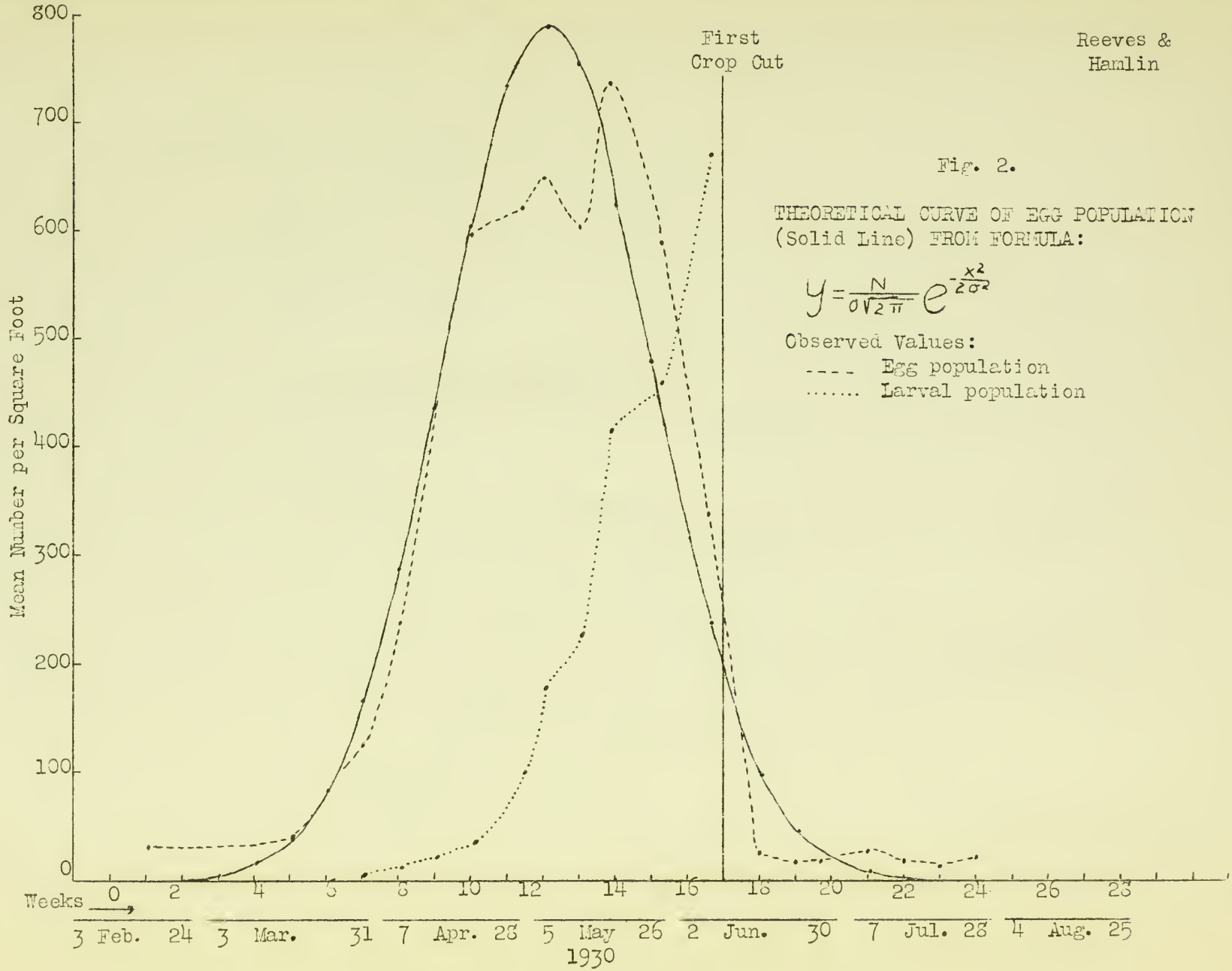


Fig. 2.

THEORETICAL CURVE OF EGG POPULATION (Solid Line) FROM FORMULA:

$$y = \frac{N}{\sigma\sqrt{2\pi}} e^{-\frac{x^2}{2\sigma^2}}$$

Observed Values:

---- Egg population

..... Larval population

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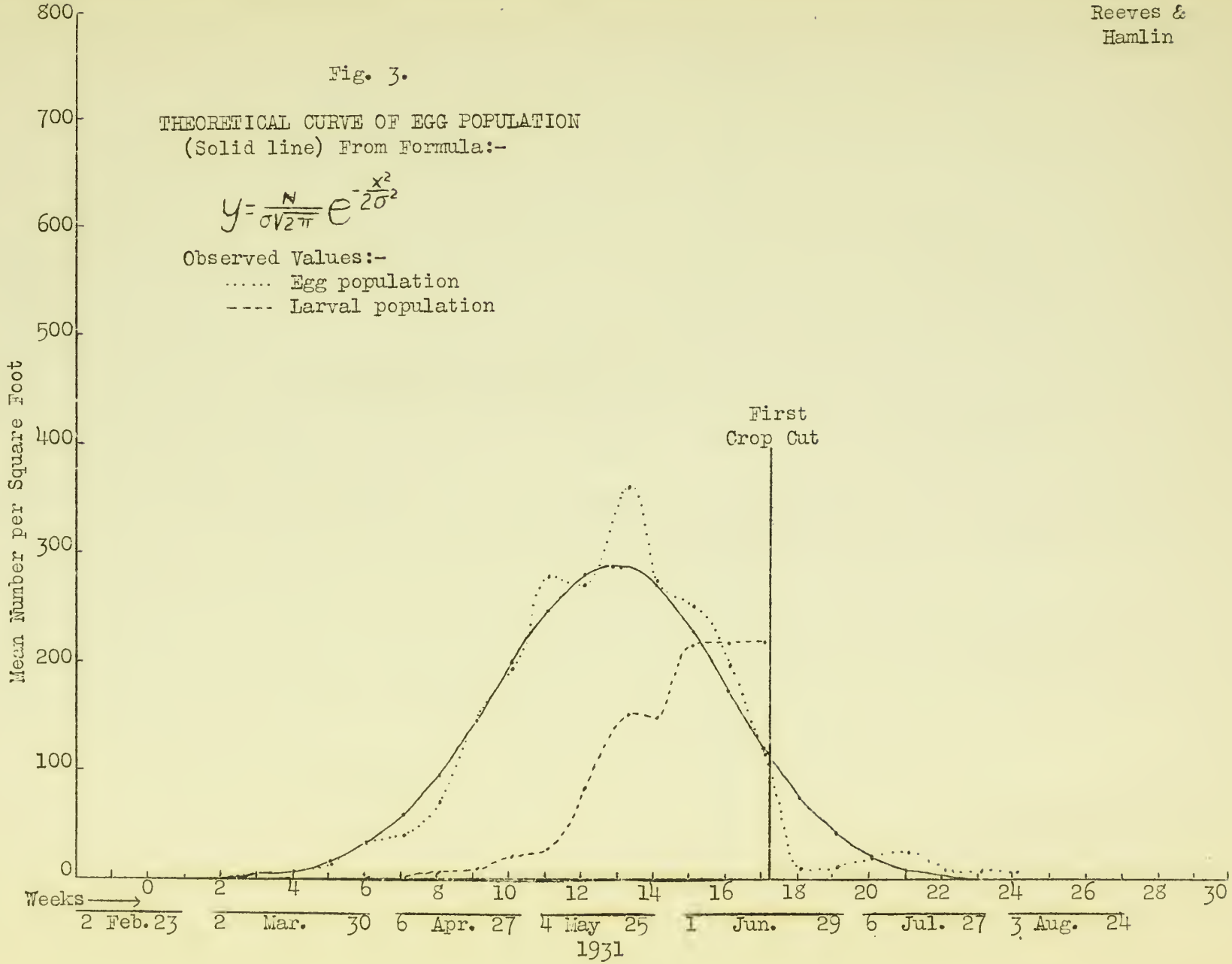
Fig. 3.

THEORETICAL CURVE OF EGG POPULATION
(Solid line) From Formula:-

$$y = \frac{N}{\sigma\sqrt{2\pi}} e^{-\frac{x^2}{2\sigma^2}}$$

Observed Values:-
..... Egg population
---- Larval population



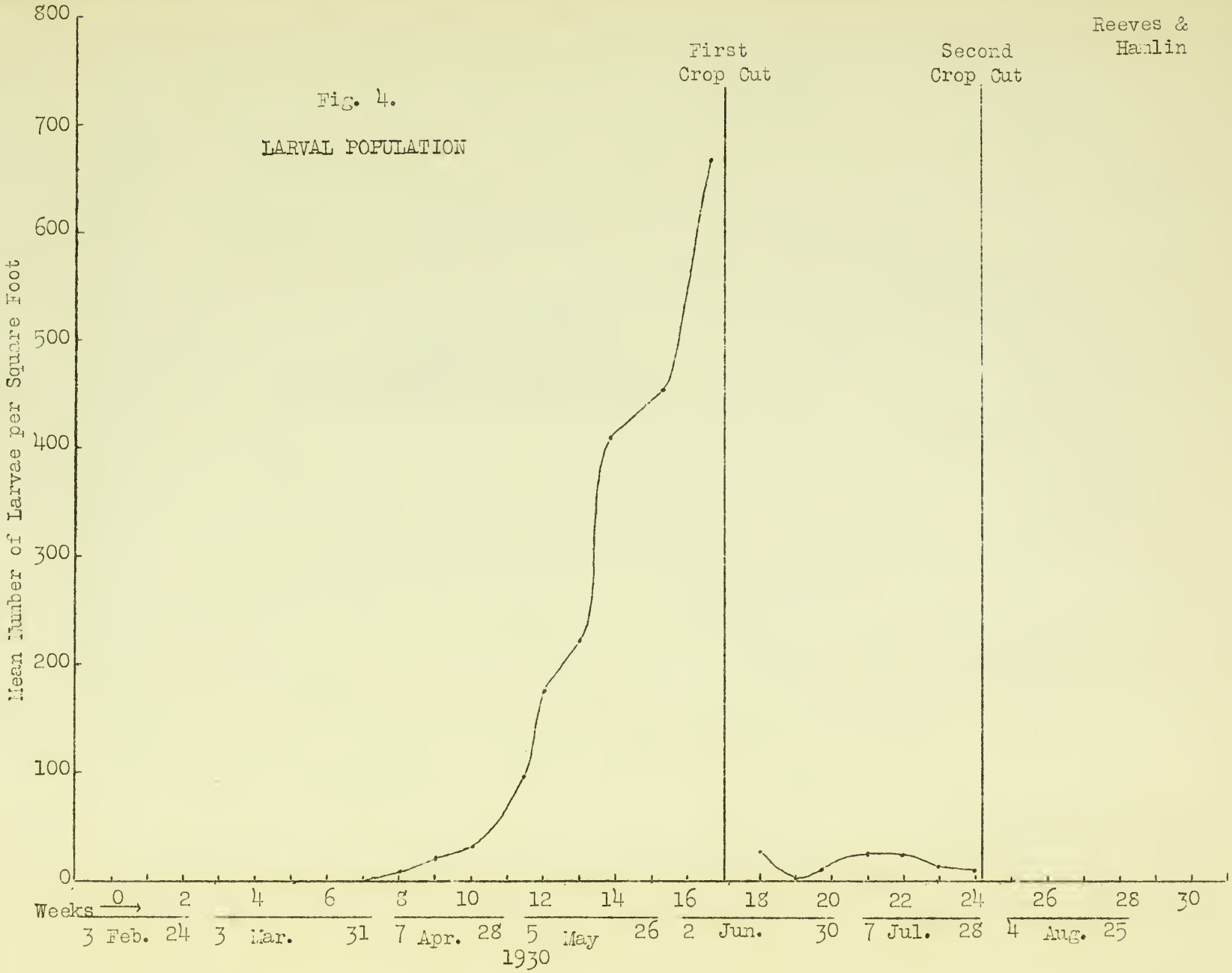


Fig. 4.
LARVAL POPULATION
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First Crop Cut
Second Crop Cut
Mean Number of Larvae per Square Foot
800
700
600
500
400
300
200
100
0
Weeks → 0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
3 Feb. 24 3 Mar. 31 7 Apr. 28 5 May 26 2 Jun. 30 7 Jul. 28 4 Aug. 25
1930

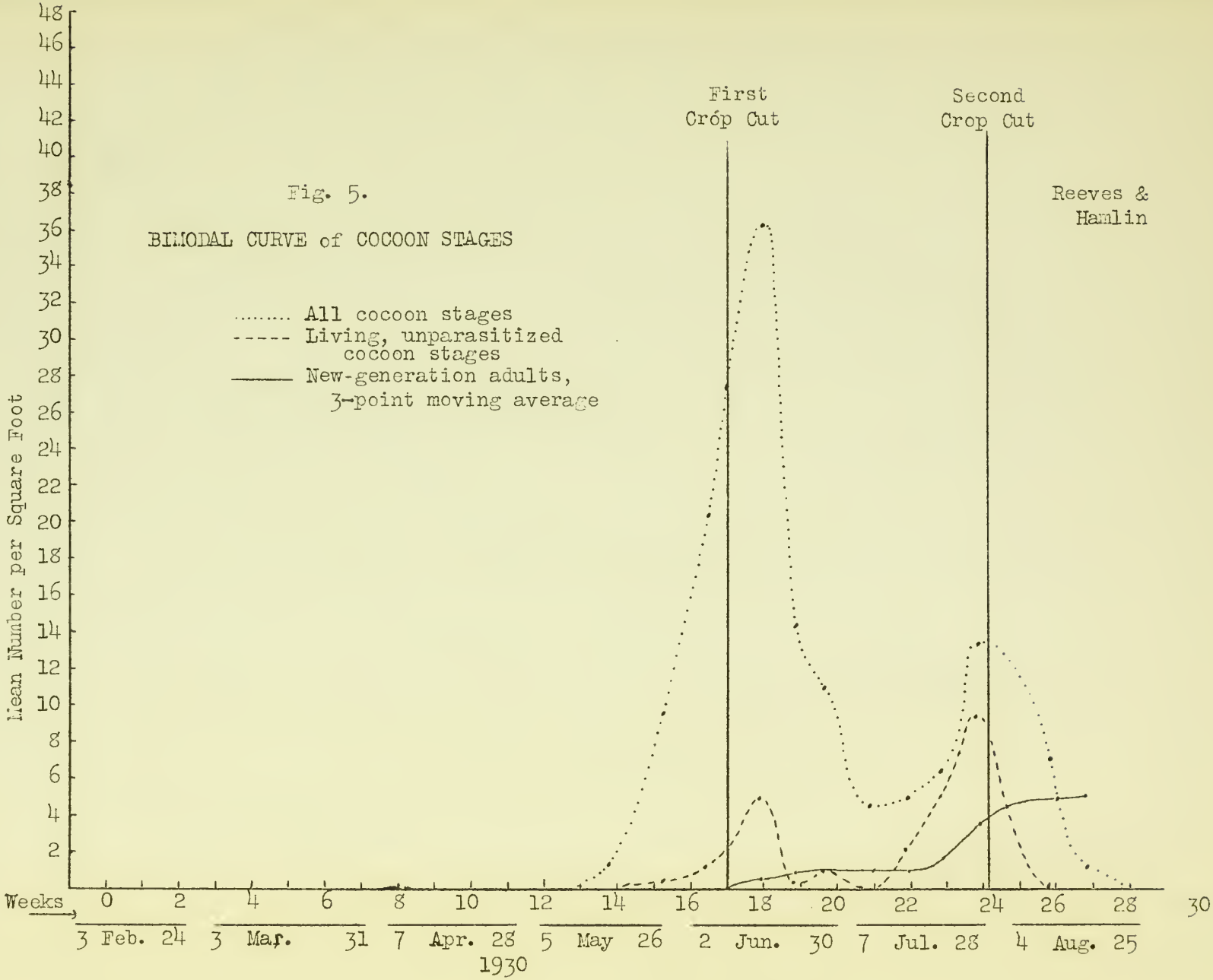
Fig. 5.
BIMODAL CURVE of COCOON STAGES
..... All cocoon stages
----- Living, unparasitized cocoon stages
——— New-generation adults, 3-point moving average
First Cróp Cut
Second Crop Cut
Reeves & Hamlin
Mean Number per Square Foot
48
46
44
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
Weeks
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
3 Feb. 24
3 Mar. 31
7 Apr. 28
5 May 26
2 Jun. 30
7 Jul. 28
4 Aug. 25
1930

Fig. 6.

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Hamlin

IMMATURE POPULATION IN RELATION TO TEMPERATURE

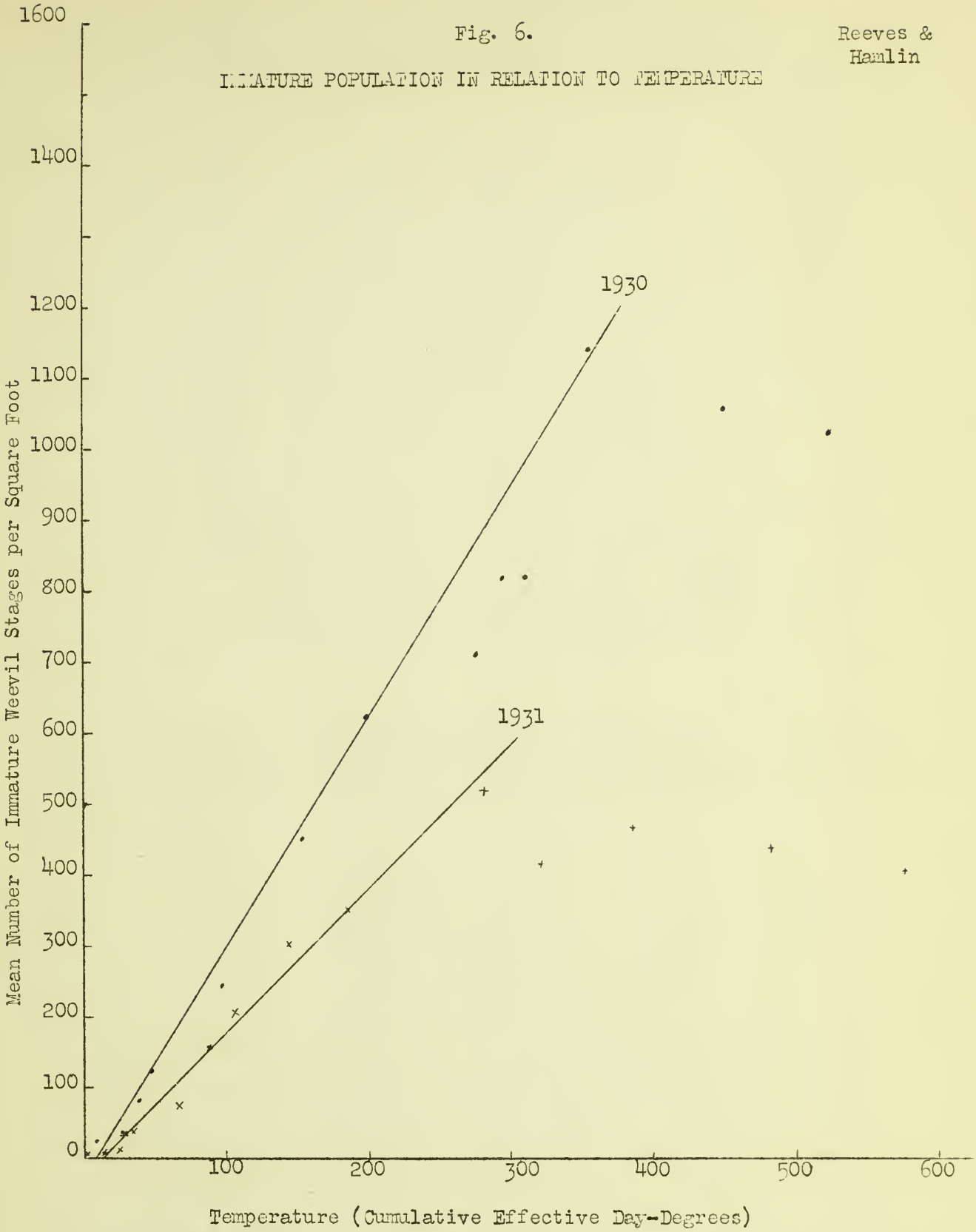
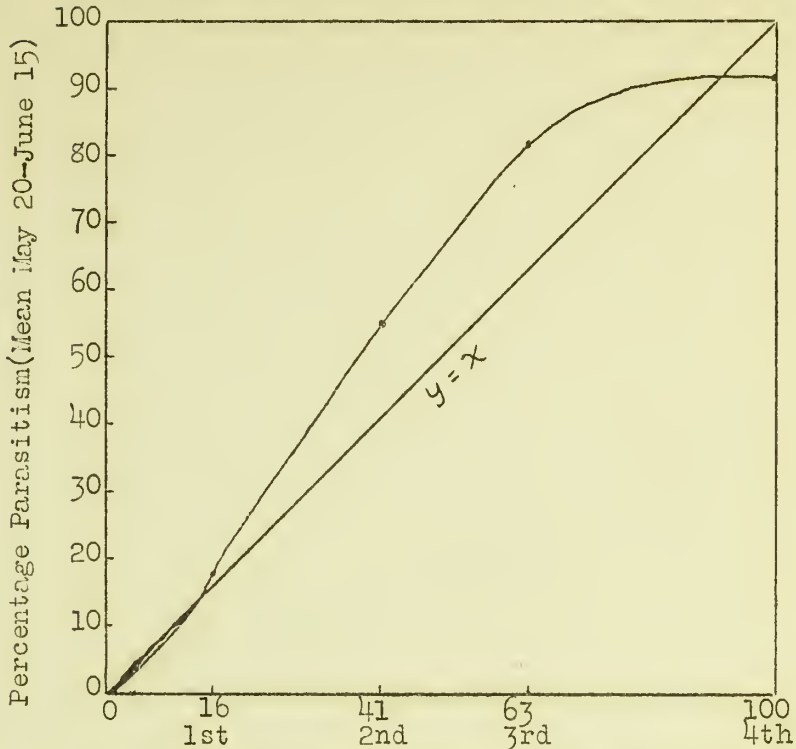


Fig. 7. Parasitism In Relation To Age Of Larvae (1931).



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Mid-points of Larval Stages Shown as Percentages of Development (time basis) 1931.

Table 1. Percentage Parasitism of Weevil:-

1931	Larvae - 1st Stage	2nd Stage	3rd Stage	4th Stage	Cocoons
April 13	0	0			
20	27.00*	58.80*	100.00*		
27	6.67±2.13	31.43±4.60 X	66.70*		
May 4	23.00±2.74 X	37.50±3.95	81.80*	100.00*	
11	30.00±2.40	58.52±2.82 X	77.80±6.60	100.00*	
20	16.80±1.60	69.00±2.00	90.50±1.60 X	96.20±1.40 X	100.00
25	30.80±2.00	60.80±2.20 X	87.20±1.80 X	93.80±2.00 X	100.00
June 1	21.60±1.80	59.20±2.40	84.60±1.80	94.20±1.20	100.00
8	9.60±2.60 X	41.00±2.80 X	73.60±2.20 X	88.00±1.40 X	98.06
15	8.00±1.60	45.30±2.40	68.60±2.20	83.60±1.60	92.76

* Number of larvae too small for calculation of PE_m

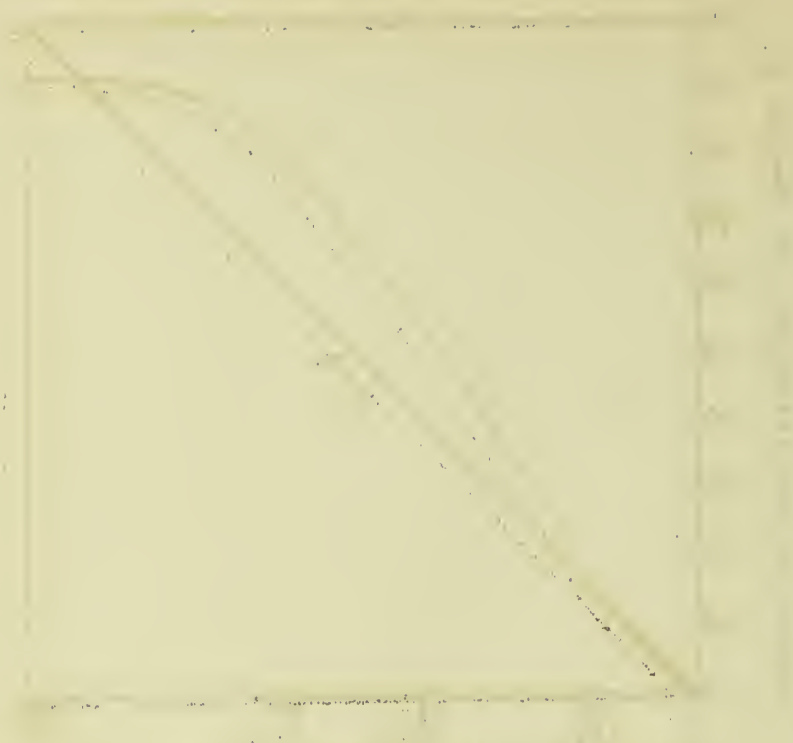
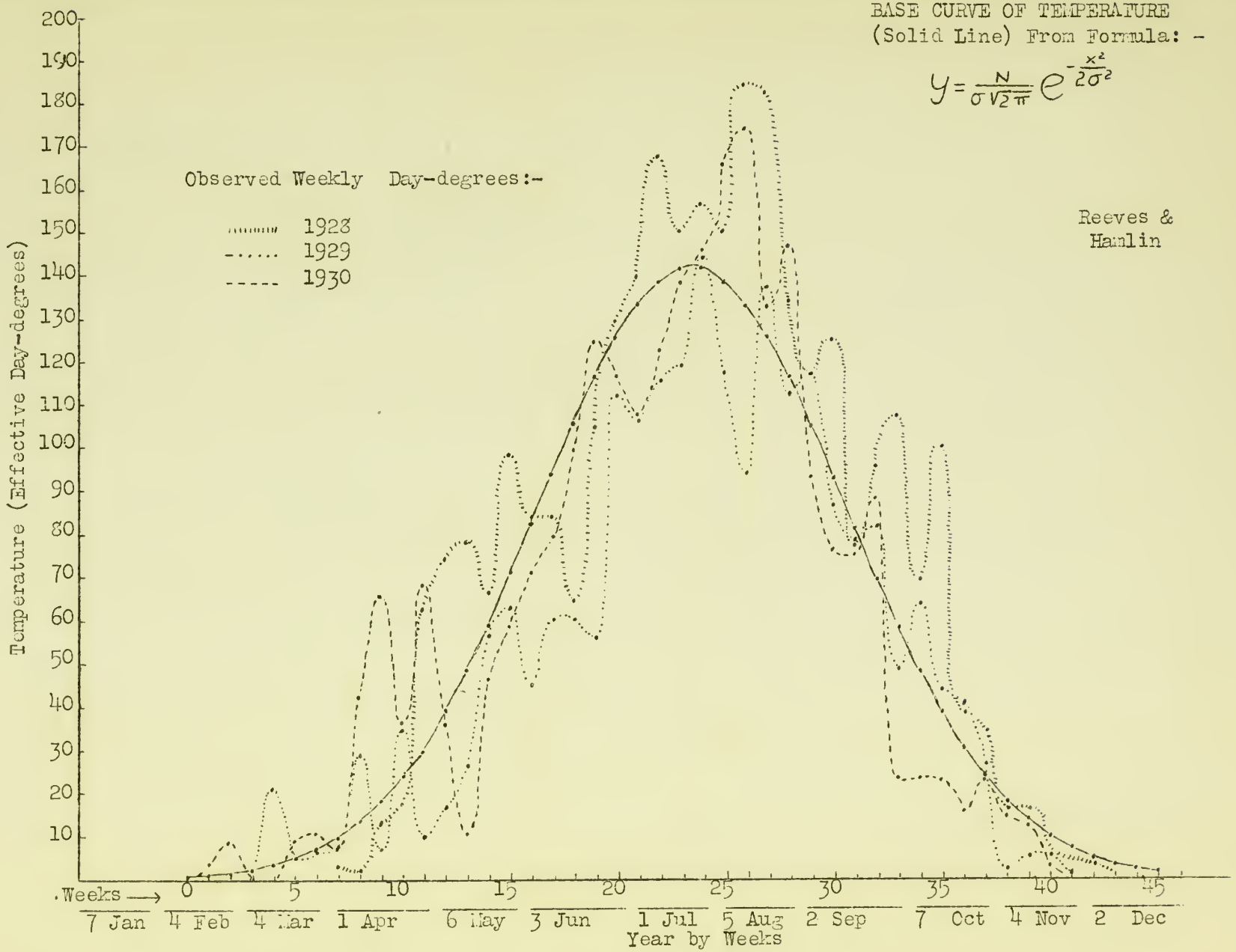


Fig. 8.

BASE CURVE OF TEMPERATURE
(Solid Line) From Formula: -

$$y = \frac{N}{\sigma\sqrt{2\pi}} e^{-\frac{x^2}{2\sigma^2}}$$



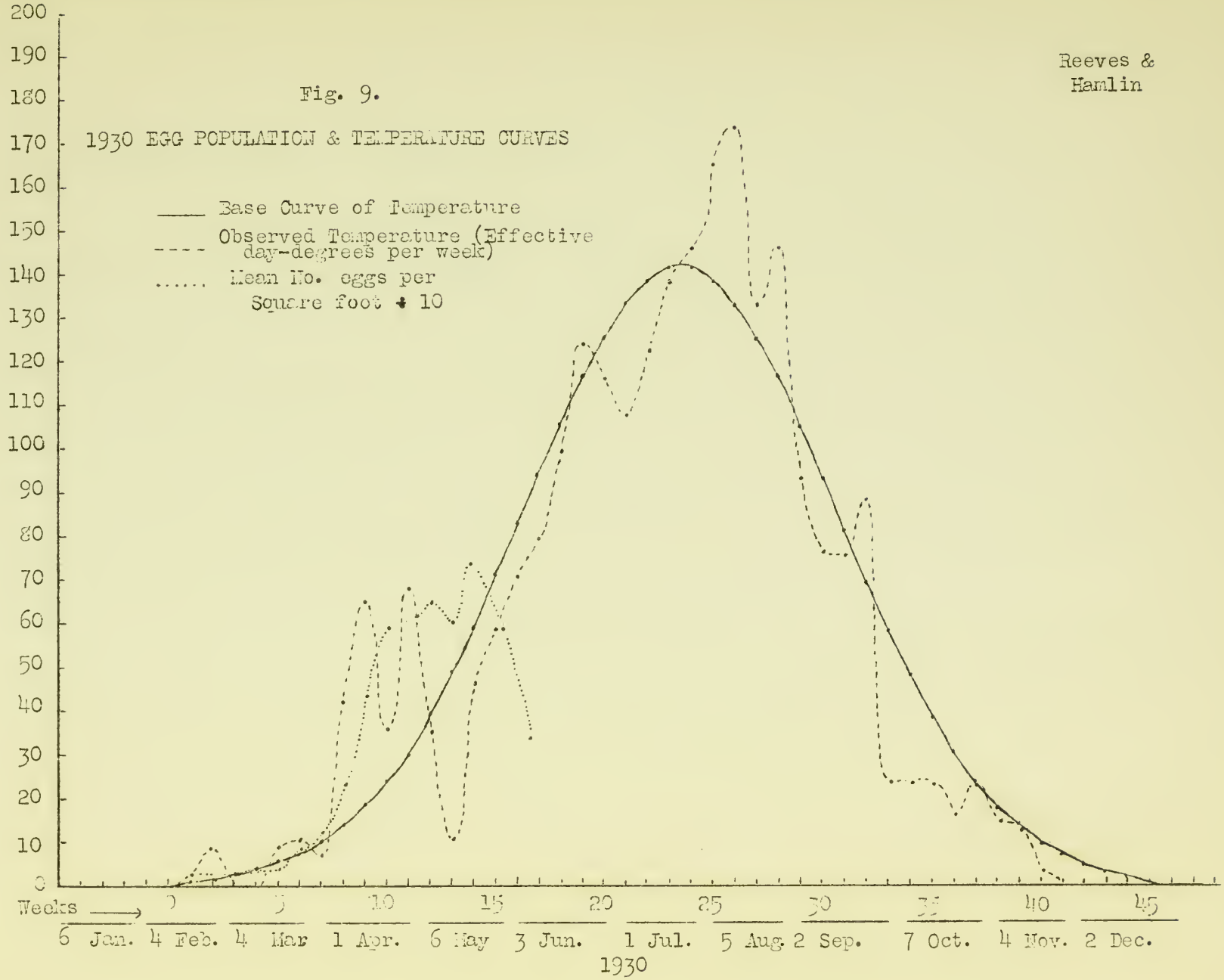


Fig. 9.
Reeves & Hamlin
1930 EGG POPULATION & TEMPERATURE CURVES
Base Curve of Temperature
Observed Temperature (Effective day-degrees per week)
Mean No. eggs per Square foot ÷ 10
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Weeks →
0
5
10
15
20
25
30
35
40
45
6 Jan.
4 Feb.
4 Mar
1 Apr.
6 May
3 Jun.
1 Jul.
5 Aug.
2 Sep.
7 Oct.
4 Nov.
2 Dec.
1930

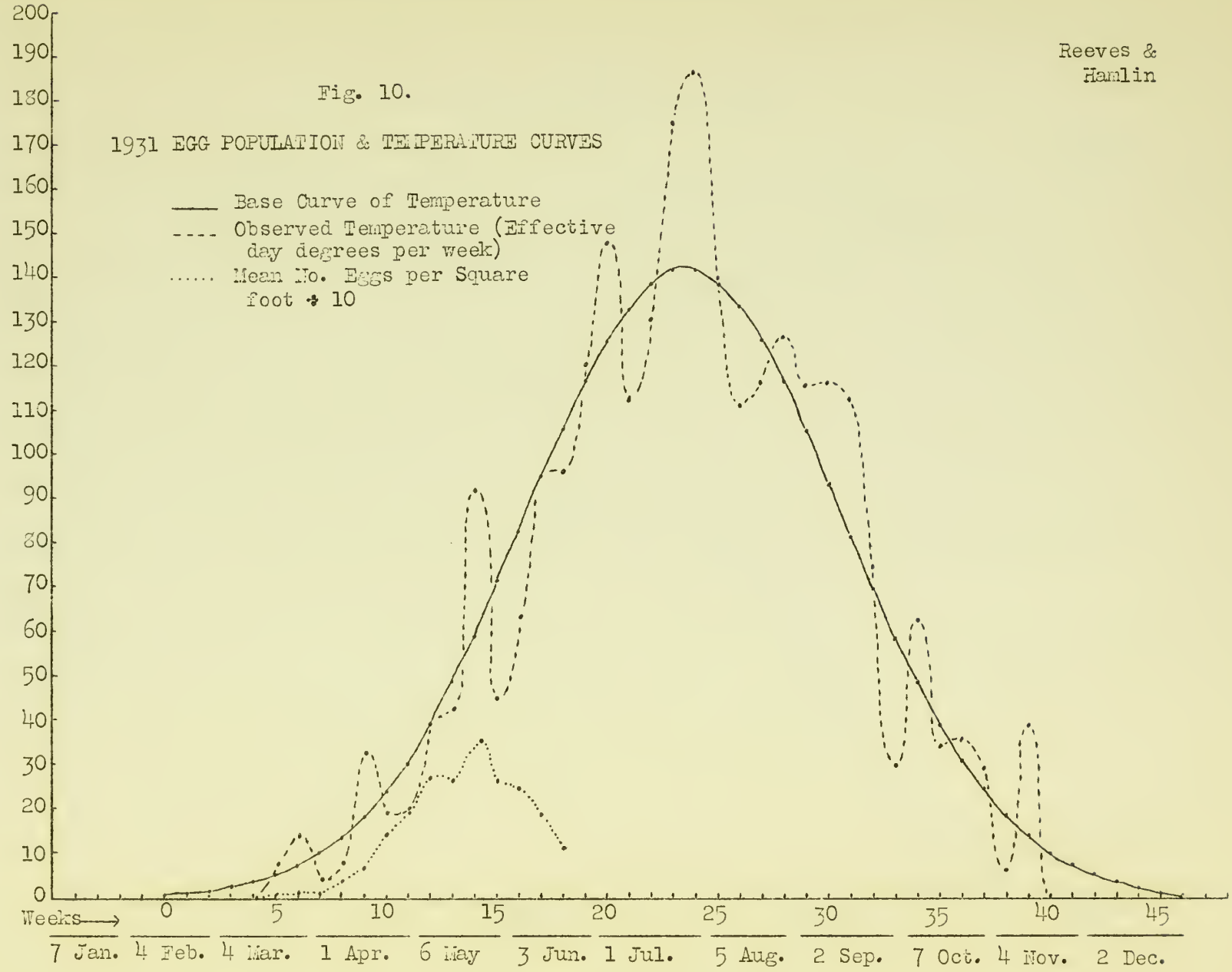
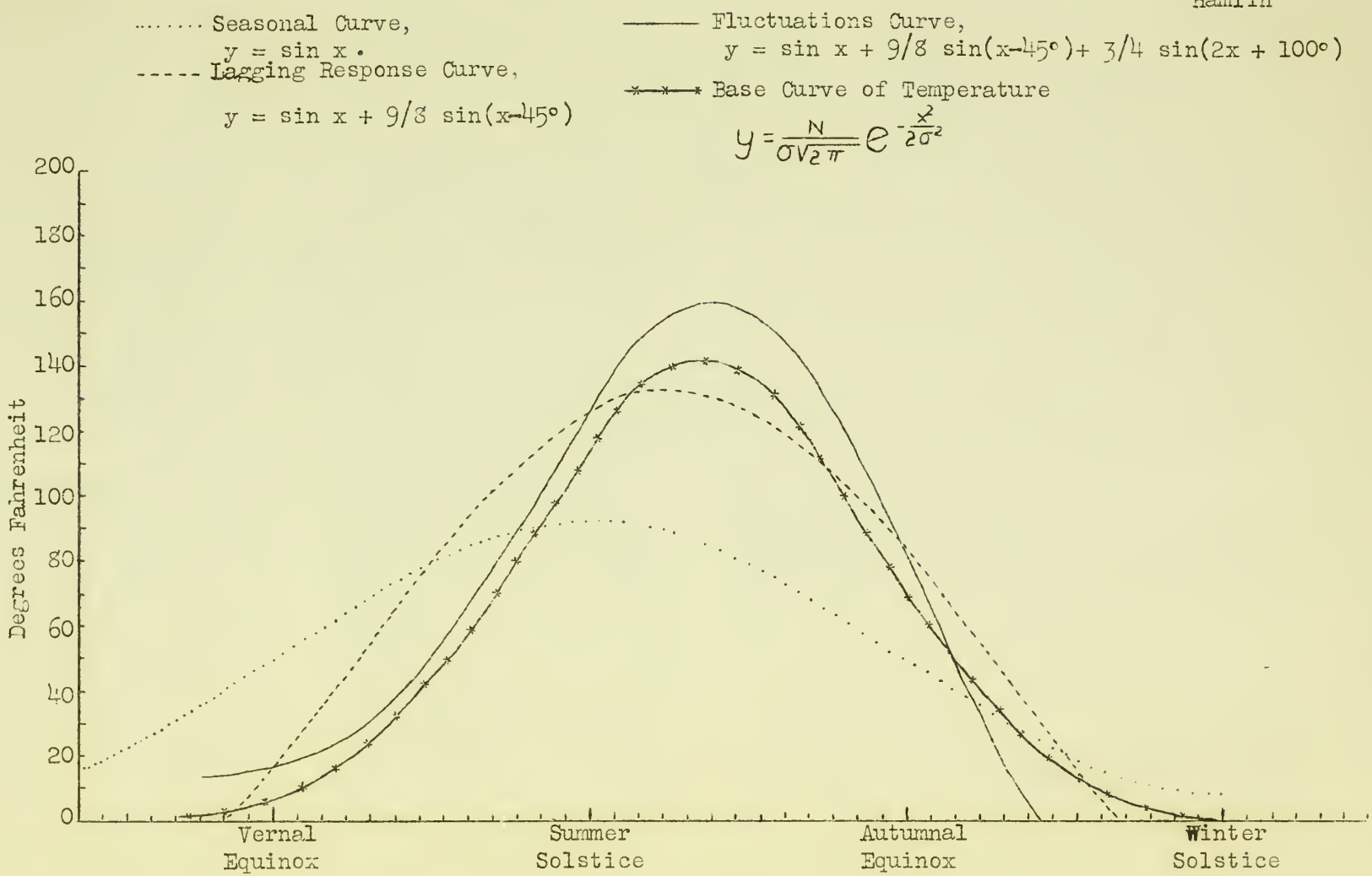


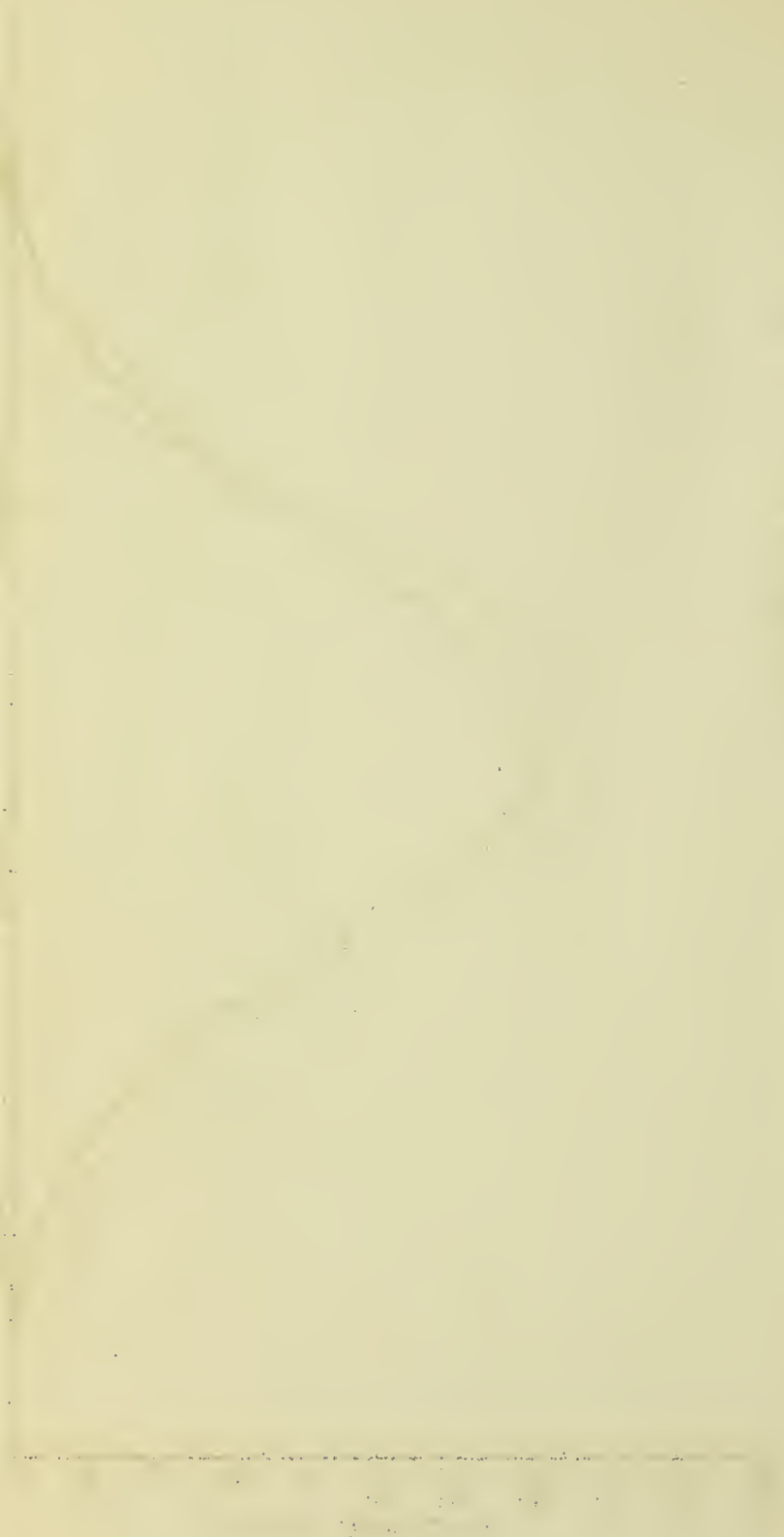
Fig. 10.
1931 EGG POPULATION & TEMPERATURE CURVES
Reeves & Hamlin
Base Curve of Temperature
Observed Temperature (Effective day degrees per week)
Mean No. Eggs per Square foot ÷ 10
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Weeks
0
5
10
15
20
25
30
35
40
45
7 Jan.
4 Feb.
4 Mar.
1 Apr.
6 May
3 Jun.
1 Jul.
5 Aug.
2 Sep.
7 Oct.
4 Nov.
2 Dec.

Fig. 11

PERIODIC TEMPERATURE CURVES

Reeves & Hamlin





The Fitting of Curves, Ralph Bunn, U. S. Bureau of Entomology.

The trend of a series of data may often be clearly indicated by fitting an appropriate curve to the plotted data. By the use of the Moving Average the effect of passing fluctuations may be ironed out, giving a smooth, even representation of the trend. Its main advantage is its flexibility, adapting itself readily to abrupt changes in rates of increase or decrease. However, for many types of data a mathematical expression may be found for the underlying law governing the trend, and a mathematical curve fitted to the series. If the data when plotted show a trend best represented by a straight line, the line may be fitted to the data by using the method of Least Squares, which gives the line from which the deviations of the separate points, when squared and totaled, are a minimum. In many cases where a straight line will not fit the data a curve of the Potential Series may represent the trend very accurately; but for ordinary purposes it should not be carried beyond the second or third power of x. The advantage of this type of work is that we may, by using it, disregard passing fluctuations and get down to the underlying principle upon which our data are based.

The Use of Standard Deviation and Probable Error, Richard C. Newton, U. S. Bureau of Entomology.

When a mass of data is too large for the human mind to grasp in its original complexity, it is usual to reduce it to its arithmetic mean. This universally used constant, however, only indicates the central tendency and it gives no idea of the scatter that exists in the original data. For instance, two groups of data may have the same arithmetic mean and yet differ markedly in their scatter. Obviously, the data with the least scatter are the more trustworthy of the two groups. The constant indicating the amount of scatter is standard deviation, designated by the Greek letter sigma. To find it, the deviations from the arithmetic mean are squared and summed and the square root of this sum extracted. It is impossible to evaluate the trustworthiness of any data unless the standard deviation as well as the arithmetic mean is determined.

Another measure of scatter closely related to standard deviation is probable error, which is .6745 times sigma. Its use can best be understood by realizing that the arithmetic mean, although called a constant, will probably vary with the number of samples taken. For instance, the mean number of insects from four samples from a given field will probably differ from a mean based on eight samples; the mean determined from twelve samples will likewise differ from the two preceeding means. Obviously, the larger the number of samples taken, the nearer the arithmetic mean approaches a fixed constant, the mean of all the insects in the field sampled. Because of this variation in the trustworthiness of the mean, each should be followed by some index of reliability. Probable error following the arith-

metic mean tells that if it is added to or subtracted from the constant to which it is appended, the two resulting figures are limits between which there is an even chance that the true arithmetic mean lies. To be significant, the arithmetic mean must be three times its probable error. Thus, probable error tells whether or not enough samples were taken in the field to approach the true conditions. The reader, seeing a mean without its index of scatter, is unable to gauge its trustworthiness, while an arithmetic mean with its probable error carries an index of reliability.

The Use of Chi^2, L. J. Jones, U.S. Bureau of Entomology. Chi^2 is a statistic used to determine the degree of agreement between two series of data. One may be observed data and the other, results calculated from a hypothesis; or the two may be separate series of observed data on the same project and dealing with similar problems.

By using Chi^2 and other mathematical tools, one is relieved of the hazard of expressing mere personal opinion upon the significance of data, and much ill-advised publication may be averted.

Chi^2 is calculated by the formula

$$Chi^2 = S\left(\frac{x}{m}^2\right)$$

in which S indicated summation, x = the difference between each value in the observed series and the corresponding one in the expected series, and m = the value in the expected series. Obviously, the closer the agreement between the two series the smaller will Chi^2 be, and as Chi^2 increases from zero to infinity, the probability that the hypothesis correctly explains the observed data approaches zero.

From a table, calculated by mathematicians, showing the relationship between different values of Chi^2 and the number of classes in the given series, is read directly the probability that the hypothesis soundly explains the observed data.

Chi^2 is a mathematical tool used purely to eliminate unscientific conclusions and is useful in biology only when the hypothesis to be tested is based upon sound biological principles.

Friday, August 31, 1 p.m., C. P. Gillette presiding.

Sugar Beet Leaf Hopper Studies at Salt Lake City, E. W. Davis, U. S. Bureau of Entomology. Mr. Davis outlined the program of work against the beet leaf hopper, especially that in the Salt Lake section. Mention was made of the breeding grounds and the native hosts, the migrations to the beet fields, the breeding of varieties of beets resistant to the leaf curl, and the systematic studies being made of the leaf hoppers.

A Note in Regard to the Collection of Various Borers from an American Elm, R. L. Parker, Kansas State College. Due to the successive series of dry summers, an American elm was killed by various boring insects. In 1929, as well as 1930, the leaves of this tree turned yellow and were prematurely dropping the latter part of August or first of September. The tree died during the season of 1930. After the tree was cut, all but the main trunk was cut for firewood and stored in a screened basement. The insects began emerging from this wood on July 10, 1931. Up to August 1st., the following wood borers were collected from the remains of this elm tree: 1 Chion cinctus(Dru.), elm and hickory borer; 35 Neoclytus (erythrocephalus) (Fab.), red-headed elm borer; 8 Saperda tridentata (Oliv.), elm borer; 332 Xylotrechus colonus (Fab.), elm and ash borer; 1480 Chrysobothris femorata (Cazt.), flat-headed apple tree borer; 55 Hymenopterous parasites (2 species); 8 Scolydidae.

The latter part of August, in the vicinity of this wood pile in the basement, many insects have died and dropped on the floor. These have not as yet been counted. The majority of these are Chrysobothris femorata.

R. L. P.

A Summer's Collecting Trip, R. H. Beamer. Dr. Beamer told of the summer's collecting trip that he, his family, and the Messers. J. O. Nottingham, H. T. Peters, L. D. Anderson and M. W. Sanderson were on for the University of Kansas. Traveling by two automobiles, one a light truck for the camp equipment and supplies, they left Lawrence, Kansas, just after the close of the spring term of the University, traveled through Colorado, Utah, Idaho and into Washington and Oregon, stopping wherever interesting insect collecting was available. They were on their return when they stopped at the Conference.

A Recent Insect Survey of Kansas by Questionnaire, Roger C. Smith, Kansas State College. During the carrying on of a Kansas Agricultural Experiment Station project on climate and insects, it has been found that the recorded information on insect abundance in this state is very incomplete. There has been no annually recorded summary of insect abundance.

A questionnaire was devised and sent to the county farm agents, entomologists in the state, including our own staff, and to about 50 selected farmers in various parts of the state. This questionnaire calls for a report by an index number on a large list of economic insects which vary in abundance from year to year. The reporters are asked to write "o" under the insects in the counties with which they are familiar when they have neither seen nor heard anything about the insect; "1" for a few individuals seen or heard of; "2" for some but no perceptible damage being done; "3" common and doing a little local damage; "4" for local outbreaks with more or less damage, and "5" for general outbreaks or as abundant as they ever get in the community. The reporters are asked to use the letter "a" when they have personally observed the insect as reported, and "b" when reporting on information of others; "3a" means the reporter has observed

personally that a certain insect is plentiful and doing some damage in a country.

This questionnaire gives a mathematical basis for the study of the abundance of insects from year to year and for correlation studies with climate. These reports were obtained in July and will be obtained again in October for each for the four months ending with the questionnaire. The response was excellent and the correlation of numerical estimations for particular counties was high. It is believed that this method is fully as good as sweeping surveys, unless the latter be undertaken on a very large scale which is costly and time-consuming. The summary of these reports will constitute the annual summary of insect abundance in the state which will form an additional and somewhat more complete record than has been made thus far.

R. C. S.

Treatment of Stored Grain for the Control of Insects, Geo. A. Dean. A general account of the development of mill fumigation during the last several years was given, taking up the use of potassium, sodium, liquid and calcium cyanide. Humidity and temperature are very important when the calcium cyanide is used. The low humidity in some sections makes its use impractical. Zyclon, a German product consisting of a calcarious substance saturated with liquid HCN, has been tested. The gas is given off very rapidly and the containers may explode in heat. The material is not on the market at the present, but a similar product sold as Discoids which consist of cardboard saturated with liquid HCN is available. The gas is here again given off rapidly and masks must be used. The liquid HCN is probably to be preferred with the Discoids next. The pot method is still valuable and is recommended for many mills. The steamships are using the Discoids generally. The heat method is still probably the best method where it can be used. Heat and HCN combined are very effective. Fumigation is not recommended for insects in flour as most of the gases are absorbed to an injurious extent. Carbon bisulphide, one pound to 25 bushels of grain and one pound to each 200 cubic feet of space above the grain is recommended, for farm graneries.

Friday evening, August 21.

Talk on Haiti, Roger C. Smith. The talk on Haiti centered about four reels of motion pictures and a few slides. The motion pictures were made by Captain Platt of the United States Marine Corps during 1928 and early 1929. They are the best pictures available on Haiti. The character of the country, the people, their manner of living, places of historical interest, the staff of the American occupation, the governmental divisions, and some of the activities of each of these services were shown by these pictures. The entomological and industrial educational program has been under the direction of the Service Technique, the service with which the speaker was connected from July, 1928 to April, 1930. Biologically, Haiti is the most interesting country of the West Indies. The country is yet in serious need of an improved agriculture, education and a stable government.

R.C.S.

A business session was held Friday afternoon just before the program. It was decided to hold the 1932 meeting at the same place, the exact time to be determined by the availability of the Lodge. However, it was thought the same week in August quite desirable.

The following report of resolutions committee was approved:

Resolved that: 1. The Eighth Annual Rocky Mountain Conference of Entomologists express its appreciation of the hospitality of the Colorado Agricultural College and the Department of Forestry for the use of the building and grounds at Pingree Park, which are so suitable for our purposes.

2. We express our thanks to the members of the Entomology Department of the Colorado Agricultural College, and in particular to Director Gillette, Dr. List and Dr. Jones, for arranging for the Conference and in making this meeting a very successful and pleasant one.

3. We note with deep regret the death of Mr. E. A. Pearson who attended the first Conference and added much to the success of that meeting by his ready wit and jovial manner.

Geo. I. Reeves
F. E. Whitehead
Roger C. Smith, Chairman

The officers elected for 1932 were: C. P. Gillette, Chairman; Paul B. Lawson, Vice Chairman; Geo. M. List, Secretary; C.R. Jones, Treasurer.

George M. List, Secretary

From the Collecting Net.

Altho high temperatures were reported from many sections frost was seen on the tops of the automobiles in camp two mornings - that is, by those that were up before the sun.

Prof. Geo. A. Dean and family spent the week before the Conference in the mountains at Green Mountain Falls, Colorado.

Prof. F. B. Paddock and family of Ames, Iowa, were in Fort Collins for several days a short time before the Conference but his recent appointment to the position of extension entomologist at Iowa State College made it impossible for them to remain for the meetings.

K. D. Arbethnot and family from Monroe, Michigan, visited Mr. Arbethnot's parents at Niwot, Colorado, before the meetings.

Dr. W. H. Larrimer, Washington, D. C., planned to be at the Conference and to go to Salt Lake City with Geo. I. Reeves and visit the Alfalfa Weevil Station but the serious grasshopper situations in several states made a change of plans necessary.

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The grasshopper interfered with the vacation plans of several entomologists and their families, that had planned on coming to Colorado.

F. E. Whitehead and family drove thru from Oklahoma, Mrs. Whitehead and children going on to Idaho by train to visit at her old home. This gave Whitehead one week following the Conference for several fishing trips.

There were not as many enthusiastic fishermen in the crowd this year as usual, but even at that two meals of trout were served.

We hope Fred Butcher from Washington, D. C., does not miscalculate on his extension schedule next year. He was in Colorado this year just one week before the meetings, but then it was probably our fault in that we did not get the dates to him early enough. (The 1932 meeting will be during the same week in August, Fred.)

Dr. E. G. Kelley and family arrived in Fort Collins on Thursday before the Conference, to visit Dr. Jones and family. They were taken to the Park the next day. It looked like Jones knew they would be good help in getting the many preliminary things done at the Lodge.

I don't see how some entomologists find so much time to perfect their horseshoe game.

Dr. Paul B. Lawson, daughter Lois and niece Miss Dorothy Osborn, drove through by auto from Lawrence, Kansas.

Geo. I. Reeves was lamenting the fact that he could not make the trip by way of his airplane. We understand that he has since then received his pilot's license so next year we will be watching in the sky for his arrival. We saw him going over the prospective landing places.

The official score in the hands of the Secretary for the Kansas-Colorado baseball game was Kansas 18, Colorado 22. Dr. P. B. Lawson was umpire.

E. W. Davis of Sugar Beet leaf hopper fame, won the horseshoe contest.

Geo. M. List, Secretary